RANGE-WIDE MONITORING OF THE MOJAVE DESERT TORTOISE (*GOPHERUS AGASSIZII*):

2015 AND 2016 ANNUAL REPORTING

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The original design for this project and considerations for optimizing it based on new information and experience were first set out in Anderson and Burnham (1996) and Anderson et al. (2001). Estimation methods were further refined during a 2008 workshop for distance sampling held by S. Buckland, L. Thomas, T. Marques, E. Rexstad, and D. Harris in Marshall, California.

Personnel from Kiva Biological Consulting (California) led by Leif Mjos, and from the Great Basin Institute (Nevada and the Beaver Dam Slope of Utah and Arizona) led by T. Christopher conducted the field surveys. The field monitors from these teams who did the hard work of collecting and verifying the data were:

2015: M. Bassett, S. Clegg, T. Corwin, J. Cox, A. Drummer, A. d'Epremesnil, S. Harris, K. Hayes, T. Hockin, G. Keyes, L. Mjos, B. O'Brien, M. Shields, C. Stirling, S. Trageser, A. Wiscovitch.

2016: K. Anderson, M. Bassett, S. Bently, J. Bodle, C. Boulden, T. Carlson, S. Clegg, T. Corwin, A. Drummer, D. Dunlop, A. d'Epremesnil, K. Forgrave, M. Fossum, J. Fowler, R. George, K. Harding, K. Hayes, A. Hedrick, K. Koch, K. Lunn, Z. Maisch, C. Michaud, L. Mjos, A. Noziglia, B. O'Brien, C. Oliver, J. Pringle, J. Riccio, M. Skandalis, C. Stirling, A. Tanner, S. Trageser, K. Van Atta, A. Wiscovitch , K. Wood.

In both 2015 and 2016, B. Sparks (GBI) provided specialized training instruction for field crews. R. Patil (inLumon) updated the electronic data-collection forms and procedures. D. Fernbach (Great Basin Institute) ran first-level quality assurance/quality control of data submitted by both field groups. T. Hutzley (Mojave Desert Ecosystem Program) provided independent review and post-processing of data. M. Brenneman (Topoworks) developed GIS tools for correctly reflecting transect paths and developed the final databases.

EXECUTIVE SUMMARY

The recovery program for Mojave desert tortoises (*Gopherus agassizii*) throughout their range in the Mojave and Colorado deserts (USFWS, 2011) requires range-wide, long-term monitoring to determine whether recovery goals are met. Specifically, will population trends within recovery units increase for a period of 25 years? In 1999, the Desert Tortoise Management Oversight Group endorsed the use of line distance sampling (Buckland et al., 2001) for estimating range-wide desert tortoise density. From 2001 to 2005 and 2007 to 2016, the USFWS has coordinated the distance sampling monitoring program for desert tortoises in 4 of the 5 recovery units. (The Upper Virgin River Recovery Unit is monitored by Utah Division of Wildlife Resources (UDWR; McLuckie et al., 2014).)

This report describes quality assurance steps and final results for the 2015 and 2016 monitoring efforts. During the first years of the project, survey effort was directed annually at all 16 long-term monitoring strata. After agency funding was severely curtailed in 2012, the decision was made to survey only in well-funded strata to generate robust estimates rather than attempting to cover more strata in a less satisfactory manner, and this approach continued as funding has steadily increased again through 2016. In 2015, crews completed 240 transects (2802 km) between 25 March and 5 May. In the course of these surveys, they reported 150 live tortoises, 137 of which were at least 180 mm midline carapace length (MCL) and used to generate density estimates. In 2016, crews completed 570 transects (6284 km) between 3 March and 26 May. They reported 347 live tortoises, 300 of which were at least 180 mm MCL.

In 2015, crews walked 20.0 km on average for each tortoise that was observed, but this number varied considerably between monitoring strata. Estimated densities in the Northeastern Mojave Recovery Unit were lower (Gold Butte-Pakoon 1.7 tortoises/km^2; Beaver Dam Slope 2.6 tortoises/km^2) than in the Chocolate Mountain portion of the Colorado Desert (7.3 tortoises/km^2), a pattern similar to past years. In 2016, the highest and lowest estimated densities were in Colorado Desert TCAs: highest in Chocolate Mountain at 8.5 tortoises/km^2 and lowest in Chemehuevi (1.7 tortoises/km^2). Fenner, Joshua Tree, Pinto Mountain, and Piute Valley were also surveyed in this recovery unit, as were Beaver Dam Slope, Mormon Mesa, and Coyote Springs Valley in the Northeastern Mojave. In the West Mojave, only Superior Cronese was surveyed, and in the Eastern Mojave only Eldorado Valley was surveyed. The encounter rate averaged 22.6 km for each tortoise that was observed.

RANGE-WIDE MONITORING OF THE MOJAVE DESERT TORTOISE 2015 & 2016

INTRODUCTION

The Mojave Desert population of the desert tortoise was listed as threatened under the Endangered Species Act in 1990. This group of desert tortoises north and west of the Colorado River are now recognized as the species *Gopherus agassizii*, separate from *G. morafkai* south and east of the Colorado River (Murphy et al., 2011). The revised recovery plan (USFWS, 2011) designates five recovery units to which decisions about continued listing status should be applied. The recovery plan specifies that consideration of delisting should only proceed when populations in each recovery unit have increased for at least one tortoise generation (25 years), as determined through a rigorous program of long-term monitoring. This report describes implementation of monitoring and presents the analysis of desert tortoise density in 2015 and 2016. A more thorough description of the background of the monitoring program, as well as estimation of population trends using data through 2014, is provided in USFWS (2015). Trends will be reevaluated after the 2019 season.

METHODS

Study areas and transect locations

Long-term monitoring strata (Figure 1) will be used over the life of the project to describe population trends in areas where tortoise recovery will be evaluated. These areas are called "tortoise conservation areas" (TCAs) in the recovery plan to describe designated critical habitat as well as contiguous areas with potential tortoise habitat and compatible management. The area associated with each critical habitat unit (CHU) is generally treated as one monitoring stratum, although the portion of Mormon Mesa CHU that is associated with Coyote Springs Valley is treated as a separate stratum. Chuckwalla CHU is also treated as dual monitoring strata, with potentially unequal sampling effort in the areas managed by the Department of Defense (Chocolate Mountain Aerial Gunnery Range, CMAGR) and by the Bureau of Land Management (BLM). New recovery units were established under the revised recovery plan (USFWS, 2011), so while making the corresponding changes to our databases we also separated the Piute and Eldorado Valleys into 2 distinct strata which are in different recovery units. Fenner Valley is in the same recovery unit but is a distinct stratum from Piute Valley to simplify reporting by state. The Joshua Tree stratum does not encompass all suitable habitat for desert tortoises in Joshua Tree National Park (JTNP). The national park designation and current boundaries just post-date the designation of CHUs, so some of the Pinto Mountains and Chuckwalla CHUs (and monitoring strata) are in the current JTNP.

In 2015, surveys were conducted exclusively in California in the AG, SC, FK, and IV strata (see Figures 1 and 4 for identification of stratum codes). In 2016, surveys were conducted in California in AG, JT, PT, CM, FE, and SC strata; and in BD, CS, EV, PV, and MM in Nevada, Arizona, and Utah. The optimal number of transects in a monitoring stratum was determined by evaluating how these samples would contribute to the precision of the annual density estimate for a given stratum (Anderson and Burnham, 1996; Buckland et al., 2001). Power to detect an increasing population size is a function of 1) the magnitude of the increasing trend, 2) the "background noise" against which the trend operates, and 3) the length of time the trend is followed (even a small annual population increase will result in a noticeably larger population size if the increase continues for many years).

Anderson and Burnham (1996) recommended that transect number and length be chosen to target precision reflected in a coefficient of variation (CV) of 10-15% for the estimate of density in each recovery unit. The CV describes the standard deviation (a measure of variability) as a proportion of the mean and is often converted to a percentage. The target CV is achieved based on the number of tortoises that might be encountered there (some strata have higher densities than others). Operationally for this species, this typically entails surveying sufficient kilometers to encounter approximately 30 tortoises in each stratum.

The actual number of transects assigned in each stratum was a function of the optimal numbers described above, as well as on available funding. Transects were selected from among a set of potential transects laid out systematically across strata, with a random origin that was established in 2007 for the lattice of transects. Systematic placement provides more even coverage of the entire stratum, something that may not occur when strictly random placement of transects is used. Once the number of transects to survey in each stratum was determined, these were selected using randomization procedures; since 2013 I have used R software to implement the Generalized Random Tesselated Stratified (GRTS) spatially balanced survey design procedure (R Core Team, 2014; Kincaid and Olsen, 2013). The US Environmental Protection Agency developed GRTS as a means to generate a spatially balanced, random sample (Stevens and Olsen, 2004). Each year GRTS was used to select planned transects with these qualities and to select a set of alternative transects that would contribute to the final sample having the same spatially representative and random properties if any planned transects were replaced due to field logistics. Because the same set of potential transects has been used since 2007, some transects are repeated between years but others may not have been selected in the past.

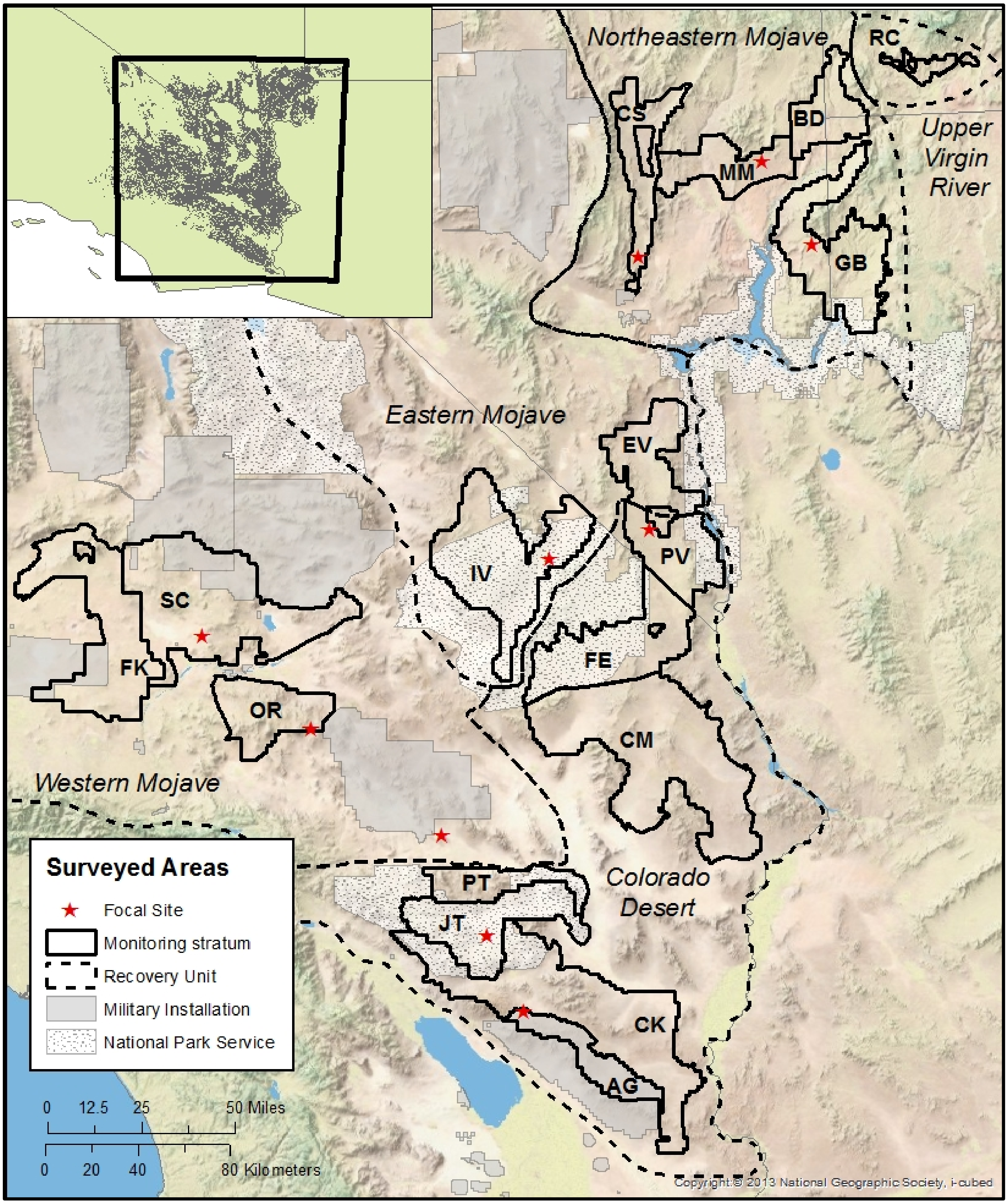

Figure 1. Long-term monitoring strata (n=17) corresponding to tortoise conservation areas (USFWS, 2011) in each recovery unit.
Stratum abbreviations are given in Table 5. Potential habitat (Nussear et al., 2009) is overlain on the southwestern United States in the extent indicator.

Distance sampling transect completion

One adaptation that tortoises have for living in the desert is to restrict surface activity to fairly narrow windows of time during the year. In general, tortoises emerge from deep within shelters (burrows) from mid-March through mid-May and then again (less predictably) in the fall. These periods coincide with flowering of their preferred food plants (in spring) and with annual mating cycles (in fall). The annual range-wide monitoring effort is scheduled to match the spring activity period for tortoises.

During this season, not all tortoises are above ground or visible in burrows. To encounter as many tortoises as possible, monitoring is scheduled for early in the day and to be completed before the hottest time of day. Because tortoises are located visually, monitoring is restricted to daylight hours. Based on past experience, we expect tortoises to become most active after 8am during March (it is usually too cool before this time), but to emerge earlier and earlier until their optimal activity period includes sunrise by the beginning of May. In May, we also expect daytime temperatures to limit tortoise above-ground activity as the morning progresses to afternoon.

Field crews completed transects during this optimal period each day. Start times were decided a week in advance, so crews arrived at transects at similar times on a given morning. However, completion times will be more variable, as a consequence of terrain, number of tortoises encountered, etc. Under normal conditions, each team walked one 12-km square transect each day. Teams were comprised of two field personnel who switched lead and follow positions at each corner of each transect, so they each spent an equal amount of time in the leader and follower positions. The leader walked on the designated compass bearing while pulling a 25 m length of durable cord; the walked path is also the transect centerline and was indicated by the location of the cord. The length of cord also spaced the two observers, guiding the path of the follower; when the cord was placed on the ground after a tortoise or carcass was detected, it facilitated measurement of the local transect bearing. The walked length of each transect was calculated as the straight-line distance between GPS point coordinates that were recorded at approximate 500 m intervals (waypoints) along the transect and/or whenever the transect bearing changed. Leader and follower each scanned for tortoises independently without leaving the centerline, and the role of the crew member finding each tortoise was recorded in the data. Although the leader saw most of the tortoises, the role of the follower was to see any remaining tortoises near the centerline, crucial to unbiased estimation of tortoise densities.

Distance sampling requires that distance from the transect centerline to tortoises is measured accurately. When a tortoise was observed, crews 1) used a compass to determine the local transect bearing based on the orientation of the 25 m centerline, 2) used a compass to determine the bearing from the point of observation to the tortoise, and 3) used a measuring tape to determine the distance from the observer to the tortoise. These data are sufficient to calculate the perpendicular distance from the observed tortoise to the local transect line. If the tortoise was outside of a burrow, was handled enough to measure midline carapace length (MCL), to determine its sex, assess its body condition (USFWS, 2012c), and to apply a small numbered tag to one scute. If a tortoise could not be measured because it was in a burrow, because temperatures precluded handling, or for any other reason, crews attempted to establish by other means whether the animal was at least 180 mm MCL, the criterion for including animals in density estimates.

Because transects are 3 km on one side, it is not unusual for that path to cross through varied terrain or even be blocked by an obstacle such as an interstate highway. In the first years of this program, smaller transects in inconvenient locations were shifted or replaced, but this compromised the representative nature of the sample. Since 2007, the basic rules for modifying transects involve 1) reflecting transects to avoid obstacles associated with human infrastructure or jurisdictions (large roads, private inholdings, administrative boundaries, etc.), or 2) shortening transects in rugged terrain (USFWS, 2012a). Substrate and access to transects can also make it difficult to complete transects during the optimal period of times, so 3) transects could be shortened to enable completion before 4pm each day.

If it was anticipated that fewer than 4 km could be walked due to difficult terrain, the transect was replaced with a transect from the alternate list that were also selected using the GRTS procedure. I assumed that the proportion of the area that was unwalkable was the same as the proportion of total planned kilometers (12 X number of planned transects) that were unwalkable. Specifics of how transect paths were to be modified for rugged terrain (shortened) or for administrative boundaries (reflected) can be found online in the current version of the handbook (USFWS, 2015).

Proportion of tortoises available for detection by line distance sampling, G_0

Basing density estimates only on the tortoises that are visible will result in density estimates that are consistently underestimated (biased low). Instead, we use telemetry to estimate the proportion of tortoises available for sampling, G_0 ("gee-sub-zero"), which was incorporated in estimate of adult tortoise density to correct this bias.

We used telemetry to locate radio-equipped tortoises that were visible as well as those that were otherwise undetectable in deep burrows or well-hidden in dense vegetation. To quantify the proportion that were available for detection (visible), telemetry technicians used a VHF radio receiver and directional antenna to locate 7-14 radio-equipped G_0 tortoises in each of 3 (2015) or 8 (2016) focal sites throughout the Mojave and Colorado deserts (Fig. 1).

Each time a transmittered tortoise was located, the observer determined whether the tortoise was visible (*yes* or *no*). Through careful coordination, observers at telemetry sites monitored visibility during the same daily time period when field crews were walking transects in the same region of the desert. Observers completed a survey circuit of all focal animals as many times as possible during the allotted time, recording visibility each time. Bootstrapped estimates of G_0 started by selecting one visibility record at random for each tortoise on each day it was located. The average visibility of all tortoise observations at a site on a given day was calculated and used to estimate the mean and variance of G_0 at that site. One thousand bootstrap samples were generated in PASW Statistics (release 18.0.2; SPSS, Inc., 2 April 2010) to estimate G_0 and its standard error.

Field observer training

Training for careful data collection and consistency between crews is fundamental part of quality assurance for this project. This training includes instruction as well as required practice time on skills such as tortoise handling, walking practice transects, and developing detection and distance-measuring techniques on a training course with tortoise models in measured locations. Chapters of the monitoring handbook are updated as needed and posted to the Desert Tortoise Recovery Office website (http://www.fws.gov/nevada/desert_tortoise/reports).

Kiva Biological (Kiva) supplied crews for monitoring in California strata in 2015 and 2016. Great Basin Institute (GBI) supplied crews for monitoring in strata in Nevada in 2016. Four of 14 personnel for Kiva had previous experience with this monitoring program in 2015, and all 12 personnel in 2016 had surveyed in the program previously. Only two of 18 surveyors for GBI in 2016 had prior experience in this program. The two teams in 2016 were trained separately by the same USFWS instructor for consistency. To accommodate logistics on Chocolate Mountain Aerial Gunnery Range, the California surveys start approximately one month earlier than those in Nevada, so it is not practical to overlap the training schedules. The training schedule is illustrated in Table 1.

Telemetry training

The primary goals of G_0 training include correct use of telemetry equipment, understanding G_0 data collection fields, observation of as many radio-equipped tortoises as possible during the day, and covering a window of observation that overlaps the day's transect observation period for each sampling area. Although all telemetry crews had some prior telemetry experience, performance on this project differs from others that do not require confirmation of the exact location of the tortoise. Unless the exact location is determined, its visibility cannot be accurately recorded. Beyond instruction and testing on use of the equipment in desert terrain, several days of practice were compulsory to be able to troubleshoot locating the tortoise and confirming the location when it could not be seen. In addition, some instruction for telemetry and transect crews overlapped to help each group better understand the purpose their data serve and how separate data types are related to the final density estimate.

Distance sampling training

Transect walkers were given classroom instruction, field demonstrations, practice transects to complete (Table 1). Ultimately each team was evaluated based on performance on a field arena outfitted with a high density of polystyrene tortoise models placed in measured locations (Anderson et al., 2001), as well as on performance meeting protocol requirements on full-day staged transects.

Polystyrene desert tortoise models were set out on the training course each year using placement instructions (vegetation or open placement, tape-measured distance along training line, and tape-measured distance perpendicular from training line). This course was used to determine whether 1) individual teams are able to detect all models on the transect centerline, 2) whether their survey techniques yield useful detection functions, and 3) whether they can accurately report the distance of each model from the transect centerline. For each purpose, many opportunities must be provided, so the course is populated at a very high density of models (410/km^2).

Crews were sent on transects and training lines as paired, independent observers. That is, the follower was 25 m behind the leader, with the opportunity to detect models not found by the leader. If the leader detected 80% of all tortoises that are found, the assumption was that the follower detected 80% of the tortoises that were missed by the leader. In this example, the pair together would detect 0.80 + (0.80 X (1 – 0.80)) = 0.96 of all tortoises on the centerline. These data on models were used to evaluate and correct crew performance before the field season, but were not used in any way to estimate densities of live tortoises once range-wide field surveys began.

Table 1. Training schedule for 2015.

	Trainees (Kiva Biological)		
Day/ Date	**Activity**	**Location**	**Trainer**
WEEK 1			
Saturday, 21-Mar	Transect methods overview	GBI Field Station	Allison
	Tortoise handling		Mjos
	Compass work		
	Introduction to Junos for training lines		Allison
Sunday, 22-Mar	Training Lines I (8km)	BLM Desert Tortoise Mgmt Area	Allison
	Junos – Transect database	GBI Field Station	Allison
Monday, 23-Mar	Full transects (12km)	LSTS	Allison
	Review training line I results	"	Allison / Fernbach
Tuesday, 24-Mar	Training Lines II (8km)	BLM Desert Tortoise Mgmt Area	Allison
	Wrap up discussion	GBI Field Station	Allison

Table 2. Training schedule for 2016 for Kiva (top) and GBI (bottom).

Team: Kiva						
	Transect trainees			**G_0 trainees**		
Day/Date	**Activity**	**Location**	**Day/Date**	**Activity**	**Location**	**Day/Date**
Wednesday, 2-Mar	Transect methods overview	GBI Field Station	Allison		Experienced telemetry technician maintaining transmitters in off-season. No training necessary	
	Tortoise handling		Mjos			
	Compass work					
	Introduction to Junos for training lines		Allison			
Thursday, 3-Mar	Training Lines I (8km)	BLM Desert Tortoise Mgmt Area (DTMA)	Allison			
	Junos – Transect database	GBI Field Station	Allison			
Friday, 4-Mar	Full transects (12km)	Large Scale Translocation Site (LSTS)	Allison			
	Review training line I results		Allison / Fernbach			
Saturday, 5-Mar	Training Lines II (8km)	BLM DTMA	Allison			
	Wrap up discussion	GBI Field Station	Allison			
Monday, 7-March	*Begin field data collection*					

Table 2. Training schedule for 2016 (continued)

Team: GBI						
	Transect trainees			G_0 trainees		
Day/Date	Activity	Location	Day/Date	Activity	Location	Day/Date
Tues, 8 Mar				Introduction to tortoise telemetry	Boulder City Cons Easement (BCCE)	Sparks
Thurs, 10 Mar				Telemetry practice	BCCE	Sparks
Fri, 11-Mar				Telemetry practice	BCCE	Sparks
Tues, 15-Mar				Telemetry practice	BCCE	Sparks
Wednesday, 16-March	Transect methods overview Compass work Intro to Junos for training lines	GBI Field Station	Allison Allison	Transect methods overview Compass work Intro to Junos for training	GBI Field Station	Allison Allison
Thurs, 17 Mar	Training Lines I (8km)	BLM DTMA	Allison	Tortoise handling	GBI Field Station	Christopher/Allison
Friday, 18-March	Tortoise handling Review training line I results	GBI Field Station	Christopher/Allison Allison / Fernbach	Training Lines I (8km)	BLM DTMA	Allison
Mon, 21 Mar	Training Lines II (16km)	BLM DTMA				
Tues, 22 Mar	Training Lines II (continued)					
Wed, 23-Mar				Telemetry practice	BCCE	Sparks
Thurs, 24-Mar				Telemetry practice	Halfway Wash	Sparks
Monday, 28-March	Tortoise Handling Training line results – Trial II		Dr. Jay Johnson Allison	Tortoise Handling		Dr. Jay Johnson
Tuesday, 29-March	Search image for tortoises Junos – Transect database	River Mtns, NV GBI Field Station	Christopher/Sparks Allison	Search image for tortoises	River Mtns, NV	Christopher/Sparks
Wed, 30 Mar	Full transects (12km), interruption		Allison	Telemetry practice	BCCE	Sparks
Thursday, 31-March	Tortoise Handling Review LSTS transects Wrap up discussion	GBI Field Station	Allison	Tortoise Handling	GBI Field Station	Allison
Friday, 1 Apr	Full transects (12km), reflected	LSTS	Christopher	Telemetry practice	Piute-Mid site	Sparks
Mon, 4-Apr				*Begin field data collection*		

Data management, quality assurance, and quality control

Two sets of data tables were maintained through the field season, organizing data collected on transects and at the G_0 focal sites. Collection data forms, paper datasheets, and databases were designed to minimize data entry errors and facilitate data verification and validation. Data were collected in both electronic and paper formats by the separate survey organizations, then combined into a single database by a single data manager provided by GBI. Data were submitted to the USFWS for evaluation at 7- 14-day intervals over the course of surveys. Data were evaluated for errors but also for consistency among crews and between field teams. Written review of the datasets was provided by USFWS to the field teams, who worked with the Phase I data manager to address any identified inconsistencies in the data and to ensure all crews applied the field protocols consistently.

Data quality assurance and quality control (data QA/QC, also known as verification and validation) was performed during the data collection (Phase I, described above), data integration, and data finalization phases. In each phase, processing steps were also implemented. For instance, in Phase I, datasheets were scanned and named to be easily associated with their electronic records. During the data integration phase (II), additional attribute fields were added to enable data from different UTM zones to be utilized simultaneously, and all fields were formatted for final processing. The third phase, data finalization, involved generation of final spatial and non-spatial data products used for analysis. Because processing steps can introduce errors each phase of QA/QC included checks of collection but also processing information. Figure 2 describes the overall data flow.

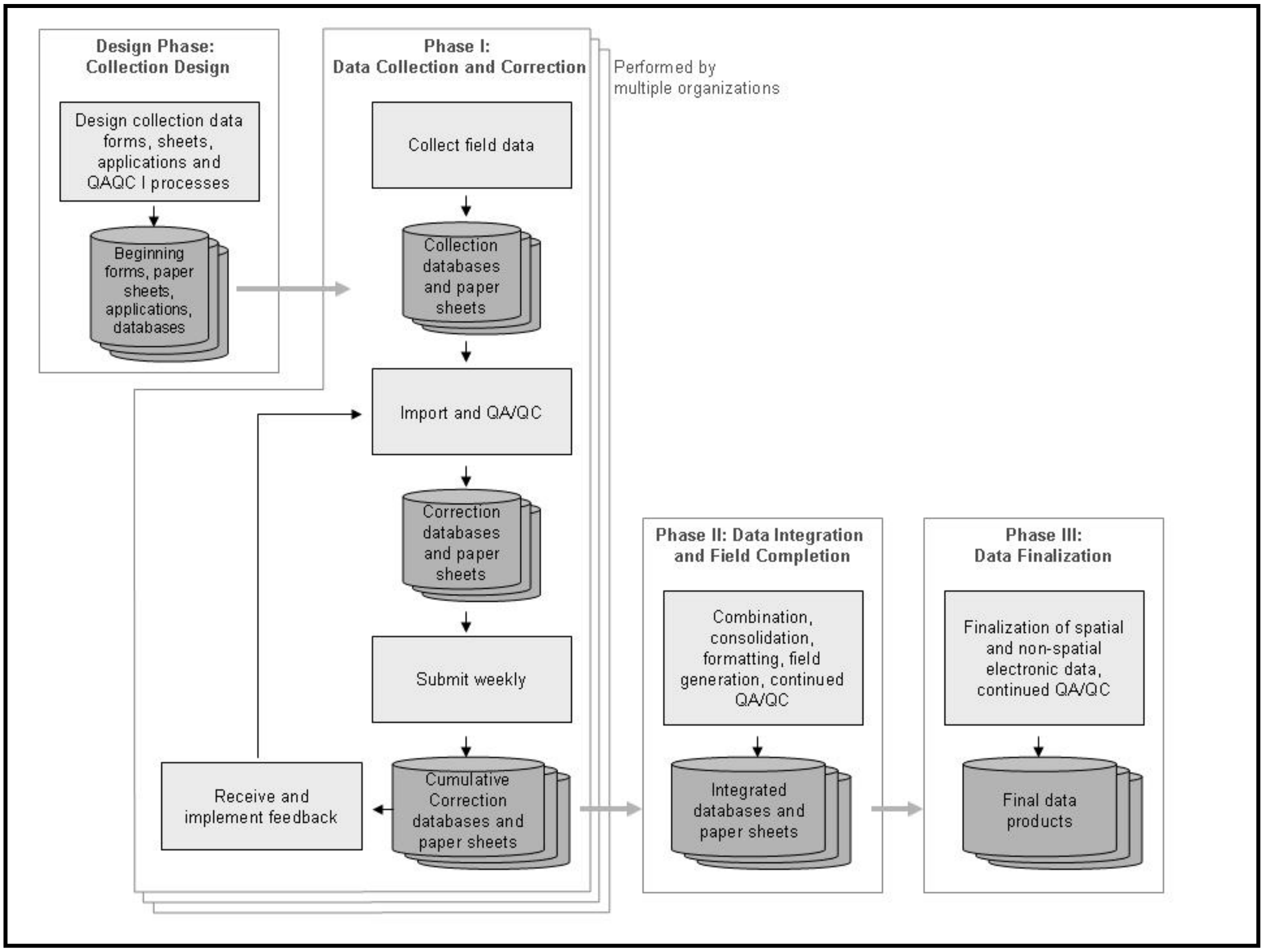

Figure 2. Data flow from collection through final products.

Tortoise encounter rate and development of detection functions

The number of tortoises seen in each stratum and their distances from the line were used to estimate the encounter rate (tortoises seen per kilometer walked) and the detection rate (proportion of available tortoises that are detected out to a certain distance from the transect centerline). Detection function estimation is “pooling robust” under most conditions (Buckland et al., 2001). This property holds as long as factors that cause variability in the curve shape are represented proportionately (Marques et al., 2007). Factors that can affect curve shape include vegetation that differentially obscures vision with distance and different detection protocols used by individual crews (pairs). I expected to develop one detection curve for each field team each year because each of the pairs on a team contributes the same number of transects to the effort, and because each team works in geographically different sites. The encounter rate is less sensitive to small sample sizes, so it was estimated for each stratum separately.

I used Program DISTANCE, Version 6, Release 2 (Thomas et al., 2010) to fit appropriate detection functions, to estimate the encounter rate of tortoises in each stratum, and to calculate the associated variances. Analysis was applied to all live tortoises at least 180 mm MCL. Transects were packaged into monitoring strata ("regions" in Program DISTANCE).

I truncated observations to improve model fit as judged by the simplicity (reasonableness) of the resulting detection function estimate (Buckland et al., 2001:15-16) as well as fit diagnostics near the transect centerline**.** Any observations that were not used to estimate detection functions were also not used to estimate the encounter rate (tortoises detected per kilometer walked). In distance sampling applications for many other species, encounter rate can be estimated with relatively high precision, but tortoise encounter rates are low enough that truncation was applied conservatively to maximize the number of observations per stratum. Using truncated data, I considered the Akaike Information Criterion (AIC) to compare detection-function models (uniform, half normal, and hazard-rate) and key function/series expansions (none, cosine, simple polynomial, hermite polynomial) recommended in Buckland et al. (2001). I also used AIC to compare models with and without the factor for field team modifying the shape of the curve.

Proportion of available tortoises detected on the transect centerline, *g(0)*

Transects were conducted by two-person crews using the method adopted beginning in 2004 (USFWS, 2006). Transects were walked in a continuous fashion, with the lead crew member walking a straight line on a specified compass bearing, trailing about 25 m of line, and the second crew member following at the end of the line. This technique involves little lateral movement off the transect centerline, where attention is focused. Use of two observers allows estimation of the proportion of tortoises detected on the line; and thereby provides a test of the assumption that all tortoises on the transect centerline are recorded ($g(0) = 1$). The capture probability (p) for tortoises within increasing distances from the transect centerline was estimated as for a two-pass removal or double-observer estimator (White et al., 1982): p = (lead–follow)/lead, where lead = the number of tortoises first seen by the observer in the leading position and follow = the number of tortoises seen by the observer in the follower position. The corresponding proportion detected near the line by two observers was estimated by $g = 1 - q^2$, where $q = 1 - p$. Figure 4 graphs the relationship between the single-observer detection rate (p) and the corresponding dual-observer detection rate (*g(0); "gee at zero"*). The actual proportion detected can be estimated, but to avoid the necessity of compensating for imperfect detection, during training field crews (pairs) are expected to detect 96% of all models within 1 m of the transect centerline. This corresponds to the leader being responsible for at least 80% of the team's detections near on the centerline in order to meet this standard and is the basis for one of the training metrics.

Few or no tortoises are located exactly on the line, and even examining a small interval (such as 1 m on each side of the transect line) results in few observations to precisely estimate *g(0)*. Instead, my test of the assumption involves examination of the lead and follow proportions starting with counts of tortoises in larger intervals from the line, moving to smaller intervals centered on the transect centerline. As the intervals get smaller the sample sizes also get smaller, but the estimates are more relevant to the area right at the transect centerline. The expectation is that the estimates should converge on *g(0)* = 1.0.

If the test does not indicate that all tortoises were seen on the transect centerline, the variance of *p* can be estimated as the binomial variance = $q(1 + q)/np$ (White et al., 1982), where n = the estimated number of tortoises within 1 m of the transect centerline, and the variance of *g(0)* is estimated as twice the variance of *p*.

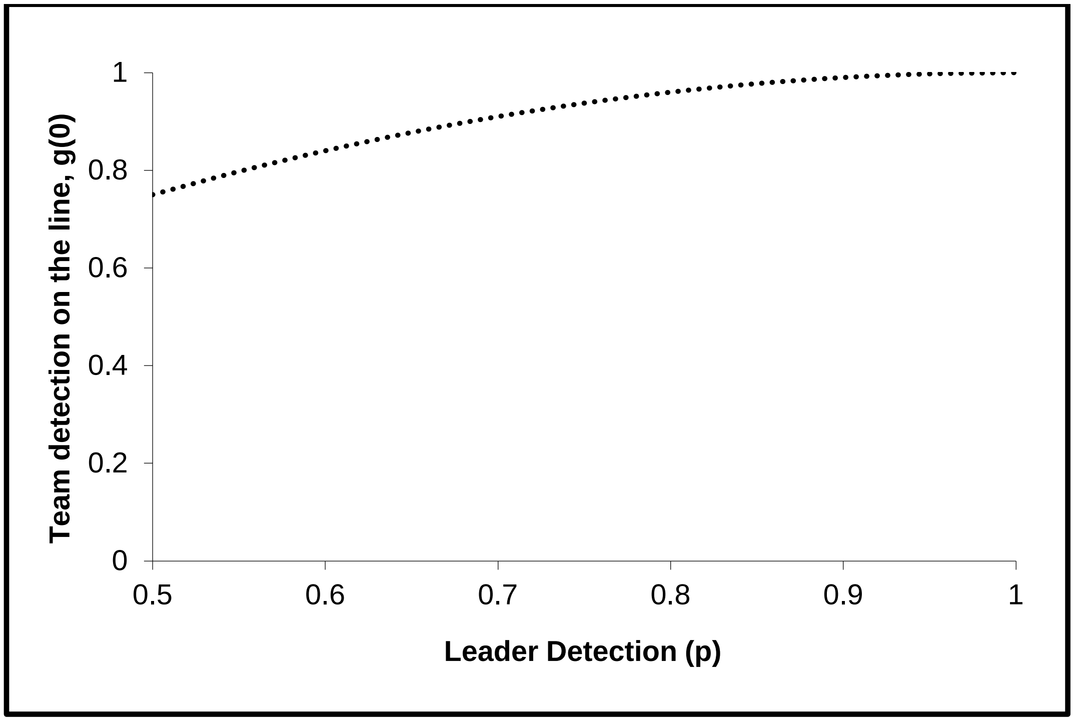

Figure 3. Relationship between single-observer detections (by the leader, *p*) and dual-observer (team) detections, *g(0)*.

Estimates of tortoise density

Each year, the density of tortoises is estimated at the level of the stratum. The calculation of these densities starts with estimates of the density of tortoises in each stratum from Program DISTANCE, as well as their variance estimates:

$$D = \frac{n}{2wLP_a G_0 g(0)},$$

where L is the total length of kilometers walked in each stratum and w is the distance to which observations are truncated, so $2wL$ is the area searched in each stratum. This is a known quantity (not estimated). P_a is the proportion of desert tortoises detected within w meters of the transect centerline and was estimated using distance assumptions in Program DISTANCE. The encounter rate (*n/L*) and its variance were estimated in Program DISTANCE for each stratum. Calculation of *D* required estimation of *n/L*, P_a, G_0, and *g(0)*, so the variance of *D* depended on the variance of these quantities as well.

Proportion of available tortoises was estimated for all strata near each G_0 site and the proportion of available tortoises detected on the transect centerline (*g(0)*) was estimated jointly for all strata. The detection function, which comes into the above equation as P_a, may be estimated jointly or separately for each team, depending on the number and quality of observations. In 2015, a single detection curve was created by pooling observations across all 4 strata for the single team (Kiva). In 2016, the two teams had very different detection patterns, so separate curves were developed for each. A schematic of the process leading to density estimates is given in Figure 4. Each of the four left-hand columns represent one contributing estimates and the rows in each column show the subsets of the data on which they are based. These estimates combined from left to right to generate stratum and recovery unit density estimates.

Tortoise encounter rate	Proportion that are visible, G_0	Detection rate, P_a	Proportion seen on the line, *g(0)*	Density	
Stratum	*Neighboring G_0 sites*	*Data collection group*	*Overall*	*Stratum*	*Recovery unit*
2015					
AG	Chuckwalla	Kiva	All data	AG	Colorado Desert
IV	Ivanpah			IV	Eastern Mojave
FK	Superior-Cronese			FK	Western Mojave
SC				SC	
2016					
SC	Superior-Cronese			SC	Western Mojave
AG	Chuckwalla	Kiva	All data	AG	Colorado Desert
PT	MCAGCC2			PT	
CM	Ivanpah			CM	
JT	Joshua Tree			JT	
FE	Piute Valley + Ivanpah			FE	
PV		GBI		PV	
EV	Piute Valley			EV	Eastern Mojave
CS	Coyote Springs			CS	Northeastern Mojave
BD	Halfway Wash			BD	
MM				MM	

Figure 4. Process for developing density estimates in 2015 (top) and 2016 (bottom). For each type of estimate, the full set of data was factored as indicated by columns.

Estimating the area of each stratum sampled and the number of tortoises in that area
Based on past experience and visual examination of GIS overlays showing topography, all assigned transects were classified as possible for completion as 12 km, shortened, or as unwalkable. These classifications before the field season were advisory only, because exact ground conditions, weather, substrate, and crew condition all affect the ability to complete a transect. If a non-standard transect (not 12 km square) is walked, crews indicate the obstacles they encountered that forced the change in protocol.

At the end of each field season, transects that were not completed as expected are evaluated, and might be reclassified. The classification is used to advise future transect completion, but also to estimate the proportion of each monitoring stratum that is actually represented by the walked transects. Proportions used in this report reflect all years of experience with this set of transects through the 2016 field season.

Crews completed all transects using the 12-km square path, completing as much of that path as possible. The calculation of unwalkable area in these strata is based on the proportion of unwalkable kilometers. The total area of the stratum that is walkable is estimated as:

$$Proportion\ walkable = \frac{transect\ kilometers\ walked}{12\ X\ transects\ completed}.$$

If a given stratum covers 5000 km^2, but only 90% was walkable, the density estimate applies to 4500 km^2, and can be used to estimate the number of tortoises in those 4500 km^2. These area estimates add another source of imprecision, so abundance estimates are slightly less precise than the density estimates from which they derive. The error of this estimate is calculated as the error for a binomial proportion.

RESULTS

Field observer training
Training in 2015 went from 21 – 24 March (Table 1). In 2016, it started on 2 March and continued through 1 April (Table 2). Tests of field detection abilities occurred toward the end of each period.

Proportion of tortoises detected at distances from the transect centerline
Table 3reports the proportion of models that were available and were detected over 16 km of transects by each team at 1-, 2-, and 5-m from the transect centerline. Teams were tested after a trial run on the detection lines or after returning crews walked practice transects to refresh the search pattern. The target for detection on the centerline is 100%, and many crews achieved this.

Table 4 reports further statistics for each team on the evaluation lines. Measurement accuracy reported in Table 4 gives the average absolute difference between the expected and measured perpendicular distances from the model to the walked line. All measurements for all models during the 2-day trial were used for this estimate, and capture inaccuracies from 1) using a compass and measuring tape to record distances to the models, plus 2) inaccurately following the trajectory of the transect. The latter source of error does not occur on monitoring transects, because the walked transect is the true transect. On training lines, measurement error increased if crew path diverged from the measured line used to place the models. The "Available Models Detected by Leader" column reports the proportion of all models that were found first by the leader. During training, this number was used to identify crews in which one of the observers is not finding at least 80% of all detected. With an 80% detection rate for the leader, a 96% detection rate was expected for the team.

Although some individual metrics were below-par (gray cells in Tables 3 and 4), all teams performed well overall so after corrective instruction to fine tune search techniques of specific crews, no pairs were rebuilt or retested. During training, detection curves were fit to each crew's set of tortoise model observations. In no case was the best-fitting model a negative exponential one without a "shoulder" describing detections near the centerline. The best-fitting detection curves were fit to the data to generate density estimates in Table 4. In Figure 5 to Figure 7, all of the crew detection curves for each field team are overlaid. Crews were not evaluated on their ability to match teammates; however, such overlays were used to focus field personnel on an additional level of conformity they could work toward. Distance sampling and development of a single detection curve from many observers is robust to the effects of pooling across observations from crews with variable search patterns, when observers contribute proportionally to the overall pattern (Marques et al., 2007).

In 2015, three of the 7 teams were new trainees. Team 6 had lower detection on the transect center line; however, this team had prior experience with other tortoise search projects, so they were given instructions to improve their search patterns before the field season. The other new trainees (Teams 2 and 3) performed equivalently to experienced teams. Team 5 had a second detection distance beyond 12 m (Figure 5) because both experienced surveyors in the role of follower were not focusing near the centerline, so this was also corrected.

All 2016 Kiva crews were experienced, and their training metrics were fine. Within the GBI crews, teams 52, 55, and 57 had the most anomalous curves (broadest shoulders) in Figure 7. Team 53 had more detections than other teams even farther from the line. The usual concern when crews are successful searching farther from the line is that they will focus less on areas close to the line; this was not the case for any of these 4 teams. They were coached on tightening their search pattern to better match other teams, but the patterns were not of concern.

Table 3. Proportion of tortoise models detected by teams within 1-, 2-, or 5-m of the transect centerline. Values that scored below the target of 0.90 at 1- and 2-m are highlighted.

Team Number	1m	2m	5m
2015			
1	0.93	0.92	0.94
2	0.87	0.93	0.95
3	1.00	1.00	0.97
4	1.00	0.96	0.85
5	0.93	0.96	0.96
6	0.79	0.81	0.87
7	0.94	0.96	0.94
Kiva/Overall	**0.922**	**0.935**	**0.925**
2016			
1	1.00	1.00	0.96
2	0.93	0.92	0.94
3	0.86	0.92	0.93
4	1.00	1.00	0.99
5	1.00	0.96	0.93
6	0.93	0.92	0.96
50	0.93	0.96	0.97
51	0.93	0.96	0.96
52	0.93	0.96	0.9
53	0.93	0.96	0.93
54	0.93	0.96	0.97
55	1.00	0.93	0.87
56	1.00	0.93	0.89
57	0.93	0.96	0.94
58	0.94	0.93	0.82
Kiva	**0.955**	**0.956**	**0.949**
GBI	**0.946**	**0.951**	**0.915**
Overall	**0.950**	**0.953**	**0.929**

Table 4. Diagnostics for individual teams after training in 2015 (top) and 2016 (bottom)

Team	Available models detected: Within 2m of centerline by leader	Available models detected: Within 2m of centerline by team	Measured v. exact model distance (m)	Estimated abundance	95% confidence interval: Lower limit	95% confidence interval: Upper limit
2015						
1	0.77	0.92	0.47	440	365.8	528.3
2	0.89	0.93	0.70	429	314.7	583.7
3	0.79	1.00	1.08	457	379.0	551.6
4	0.88	0.96	0.90	455	373.8	553.8
5	0.85	0.96	0.86	446	366.4	543.3
6	0.73	0.81	1.08	434	362.4	519.9
7	0.92	0.96	0.87	444	361.0	546.5
Kiva/Overall	**0.833**	**0.935**	**0.851**	**443.5**		
2016						
1	1.00	1.00	0.86	508	423.5	608.2
2	0.85	0.92	1.09	476	396.1	572.4
3	0.92	0.92	0.93	445	368.1	538.9
4	1.00	1.00	0.72	435	392.9	482.2
5	0.93	0.96	0.82	409	347.1	481.8
6	0.85	0.92	0.76	415	352.3	489.1
50	0.81	0.96	0.92	417	371.1	469.4
51	0.81	0.96	1.01	473	412.7	542.4
52	0.93	0.96	1.00	362	315.0	416.5
53	0.81	0.96	0.79	403	356.5	454.4
54	0.85	0.96	1.08	524	442.5	620.3
55	0.79	0.93	0.89	365	297.7	447.6
56	0.86	0.93	0.83	448	369.1	543.1
57	0.93	0.96	0.91	398	340.0	464.8
58	0.86	0.93	0.94	419	303.8	578.4
Target	**>0.80**	**>0.90**	**<1.00**	**410**		
Kiva	**0.925**	**0.956**	**0.86**	**448.1**		
GBI	**0.848**	**0.951**	**0.93**	**423.2**		
Overall	**0.879**	**0.953**	**0.90**	**433.1**		

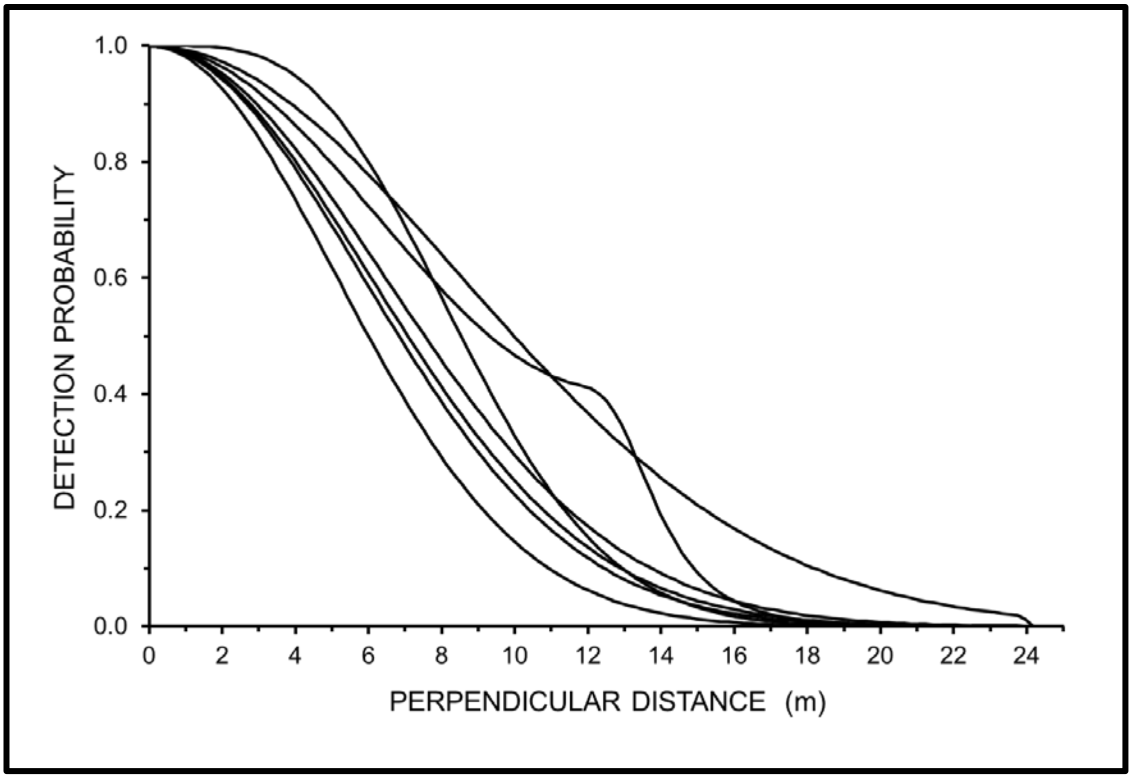

Figure 5. Detection curves for each of the 2015 Kiva teams during training. Each curve is based on a 16 km trial with approximately 100 detections.

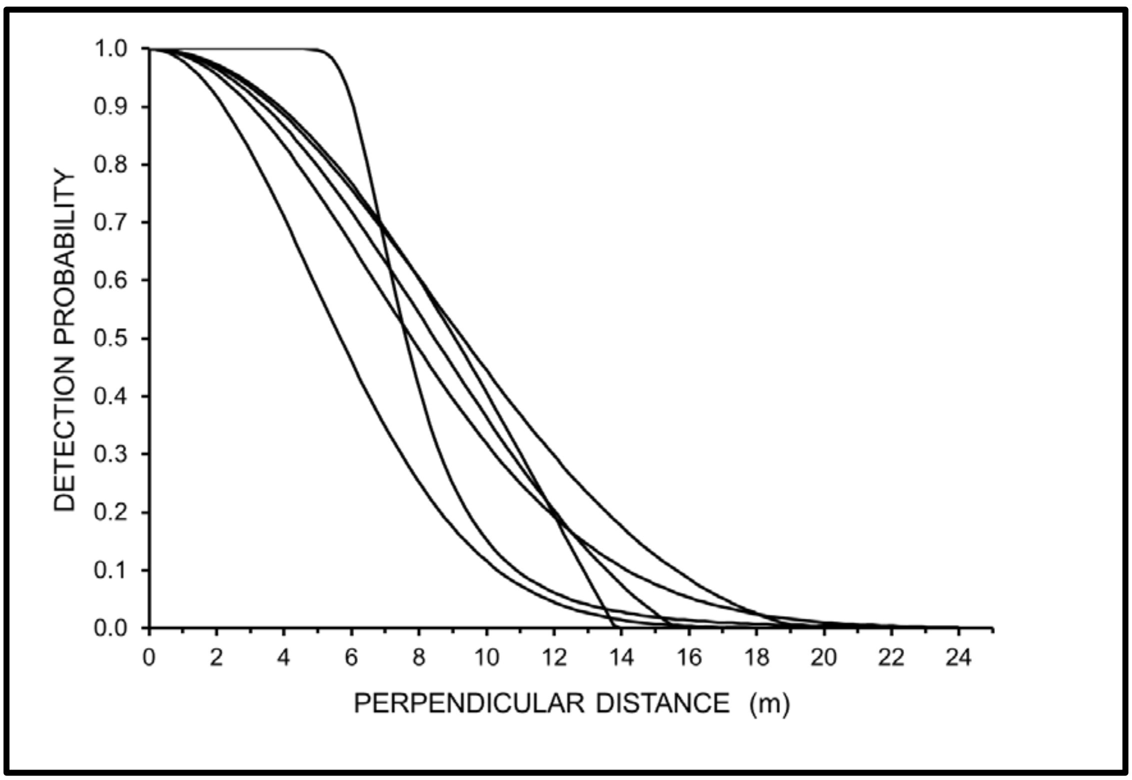

Figure 6. Detection curves for each of the 2016 Kiva teams during training. Each curve is based on a 16 km trial with approximately 100 detections.

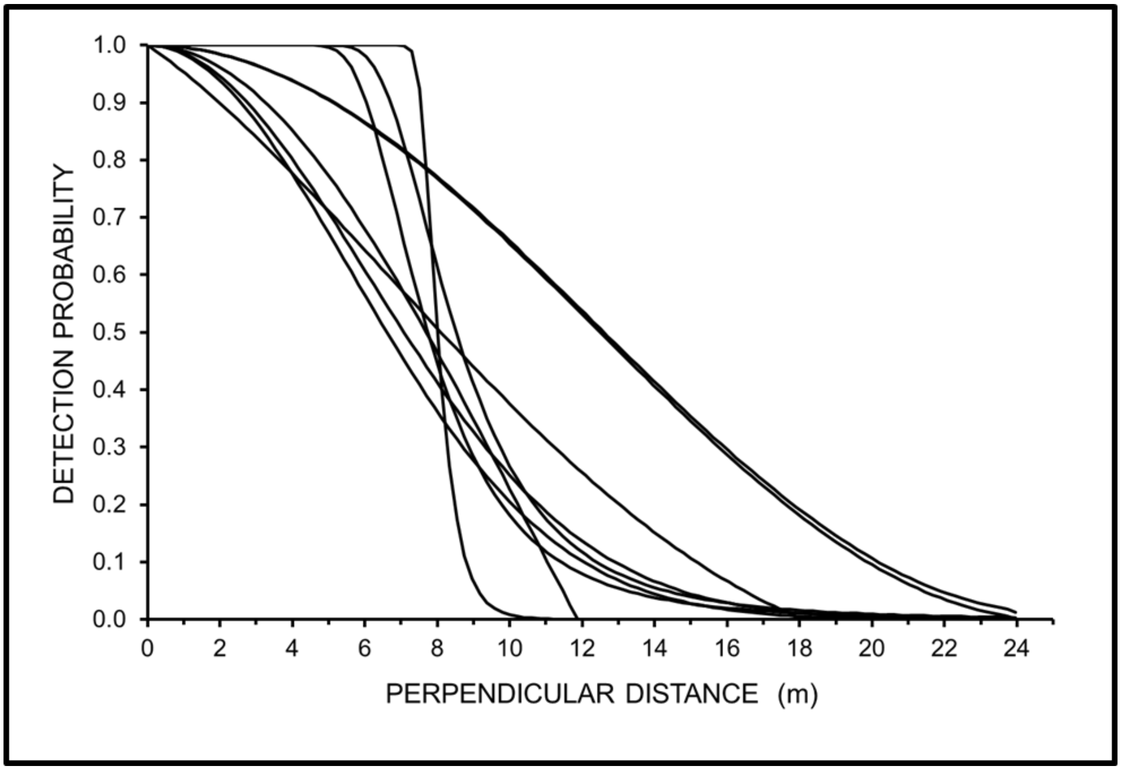

Figure 7. Detection curves for each of the 2016 GBI trainee teams. Each curve is based on a 16 km trial with approximately 100 detections.

Quality assurance and quality control

There were 6922 (15,924) transect records and 908 (3011) G_0 records associated with the monitoring effort in 2015 (2016). The first data specialist worked with the field teams to resolve 128 (565) cases with fields that were inconsistent with constraints and expectation. After this phase of QA/QC had finished verifying and validating the information in these databases, Phase II provided independent review, repackaged tables into their final configuration, and added some spatial information. A surprisingly high 4784 (7387) issues remained or were discovered in the third (final) phase of QA/QC. Only 234 (505) were errors created by the field crews (sometimes faulty equipment or crews otherwise entering electronic data after their transect was completed, other times data entry error), of which all but 19 (43) were corrected with recourse to paper datasheets. The remaining errors in 2015 indicated a failure to comply with protocols (e.g., ID tags not attached because epoxy tube broke), not because the data were erroneous. In 2016, the Junos occasionally failed to save individual waypoints (always when pictures were taken) so there were many cases of delayed entry of electronic information for which the cause was aging data collection hardware, not team error.

Another 4550 (6882) errors were processing errors that were identified and corrected before the final database products were created. "Processing steps" refer to any manipulation that occurs after the data have been collected. The majority of errors in 2015 and 2016 involved mistakes when creating new fields. These errors were repaired before creating the final databases.

Data for these and previous years are available at http://psw.databasin.org/galleries/af8e55a0197a4c95a3120b278075a2b1.

Transect completion

Tables 5 and 6 report the number of assigned and completed transects in each stratum in 2015 and 2016. In 2015, all assigned transects were completed, or alternates were walked in their stead. In 2016, Kiva was unable to complete one assigned transect due to flooding, so they completed an additional transect in a different stratum. The Great Basin Institute inadvertently failed to replace one assigned transect, and once they realized this did not have time before the end of the field season to add a replacement transect.

Tables 5 and 6 also indicate the number of assigned transects that could be completed as standard square 12-km transects or by reflecting around property boundaries and infrastructure (column 4). An additional number (column 5) were shortened and represent more rugged terrain. Finally, some transects were considered unwalkable (column 6). Figures 6 to 9 show locations of transects and observations of live tortoises.

Table 5. Number and completion of transects in each stratum in 2015.

Stratum	Assigned transects	Assigned and alternate transects completed*	Assigned, completed 12k	Assigned, completed shortened	Assigned, judged unwalkable*
AG	36	36	25	5	6
FK	60	60	53	2	5
IV	74	74	66	5	3
SC	70	70	55	12	3
Total/Kiva	240	240	199	24	17

*Assigned transects that were not walked were replaced by alternates.

Table 6. Number and completion of transects in each stratum in 2016.

Stratum	Assigned transects	Assigned and alternate transects completed*	Assigned, completed 12k	Assigned, completed shortened	Assigned, judged unwalkable*
BD	28	28	19	8	1
CS	54	54	26	15	11
EV	90	89	62	16	12
MM	42	42	26	9	5
PV	51	51	37	6	7
GBI	265	264	170	54	36
AG	36	36	19	6	2
CM	70	70	59	9	2
FE	50	50	45	2	3
JT	40	41	15	11	12
PT	40	40	9	16	14
SC	70	69	49	17	3
Kiva	306	306	196	61	36
Total	571	570	366	115	72

*Assigned transects that were not walked were to be replaced by alternates. Since completion of the Lincoln County HCP, 2 assigned transects in CS were removed from planning. Ten walkable assigned transects in SC and AG were replaced due to planning considerations on military installations. In JT, MM, and PV, flooding or hike time (sometimes into designated wilderness) precluded completing 5 walkable transects. One assigned transect in PV was inadvertently not replaced.

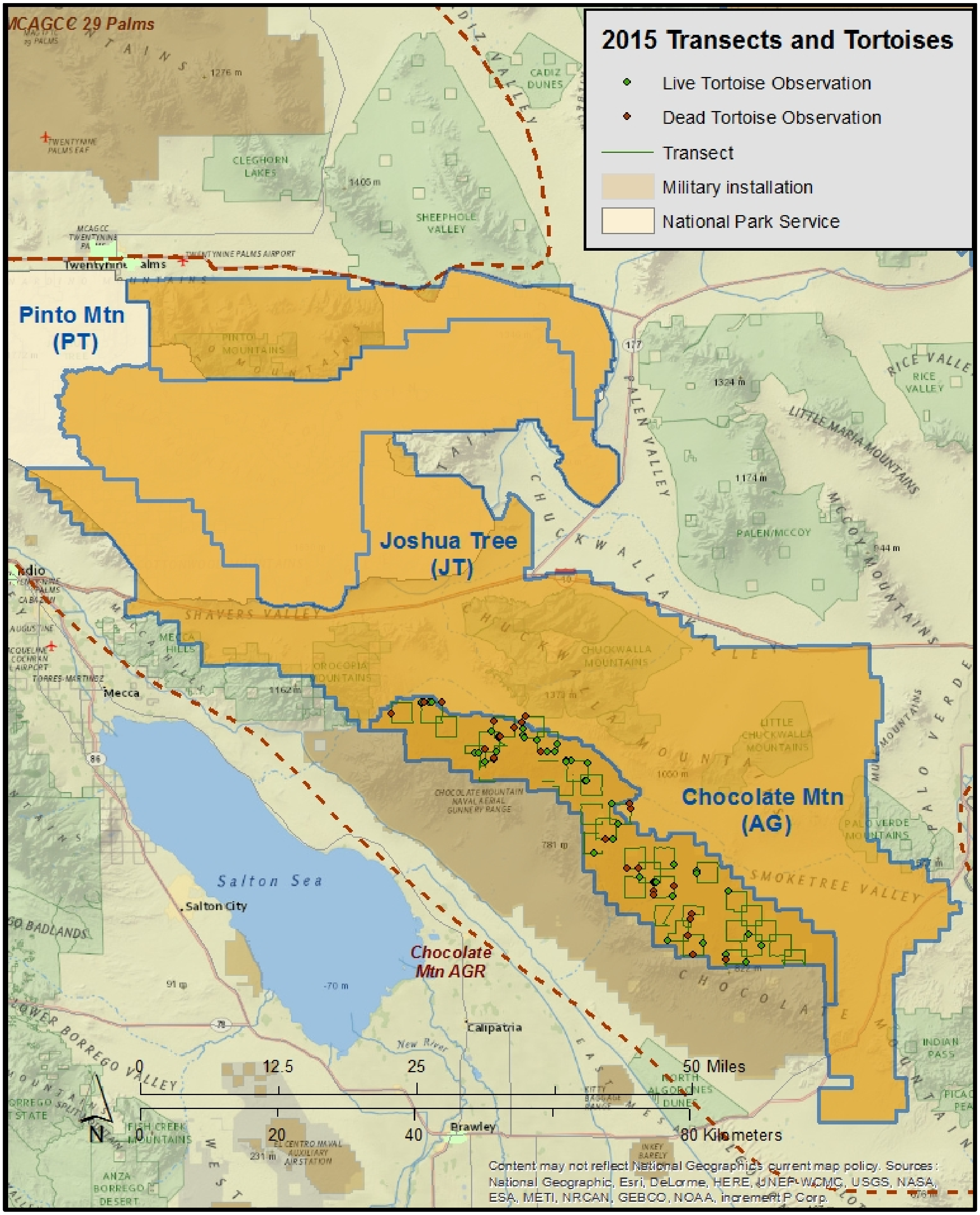

Figure 8. Distribution of distance sampling transects and live tortoise observations in 2015 in the Chocolate Mountain Aerial Gunnery Range stratum in the Colorado Desert Recovery Unit.

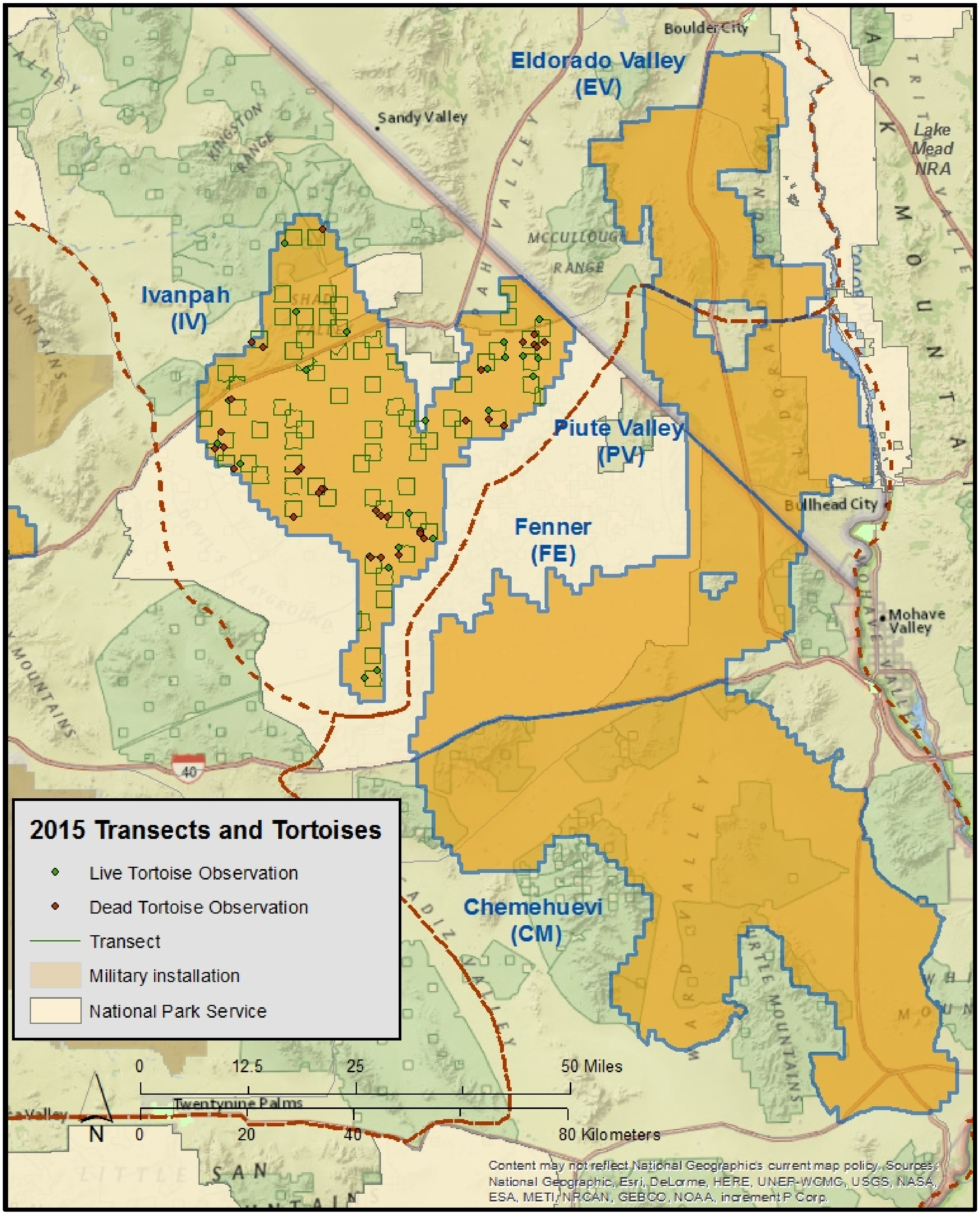

Figure 9. Distribution of distance sampling transects and live tortoise observations in 2015 in the Ivanpah stratum of the Eastern Mojave Recovery Unit.

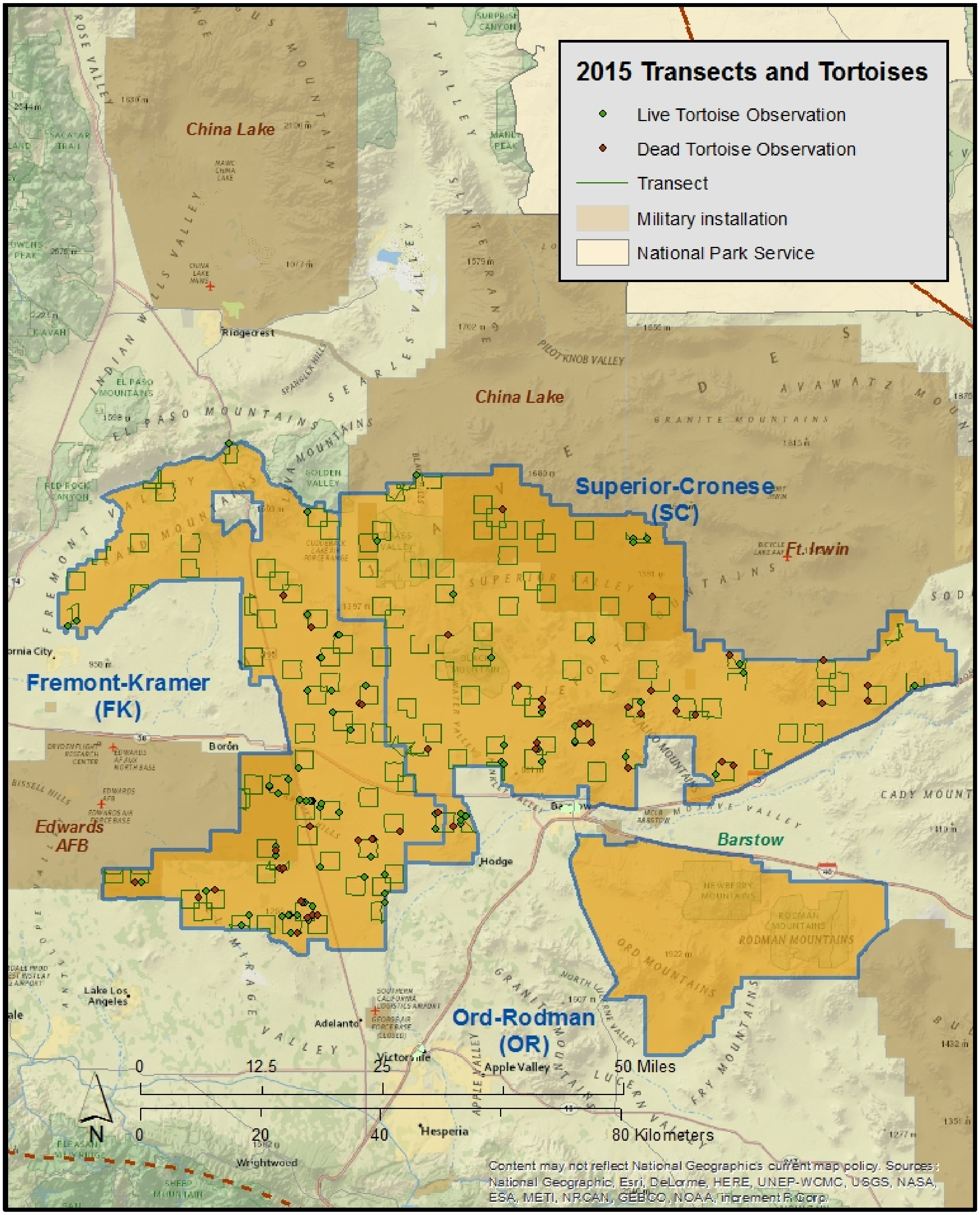

Figure 10. Distribution of distance sampling transects and live tortoise observations in 2015 in the Western Mojave Recovery Unit (Fremont-Kramer and Superior-Cronese monitoring strata were surveyed).

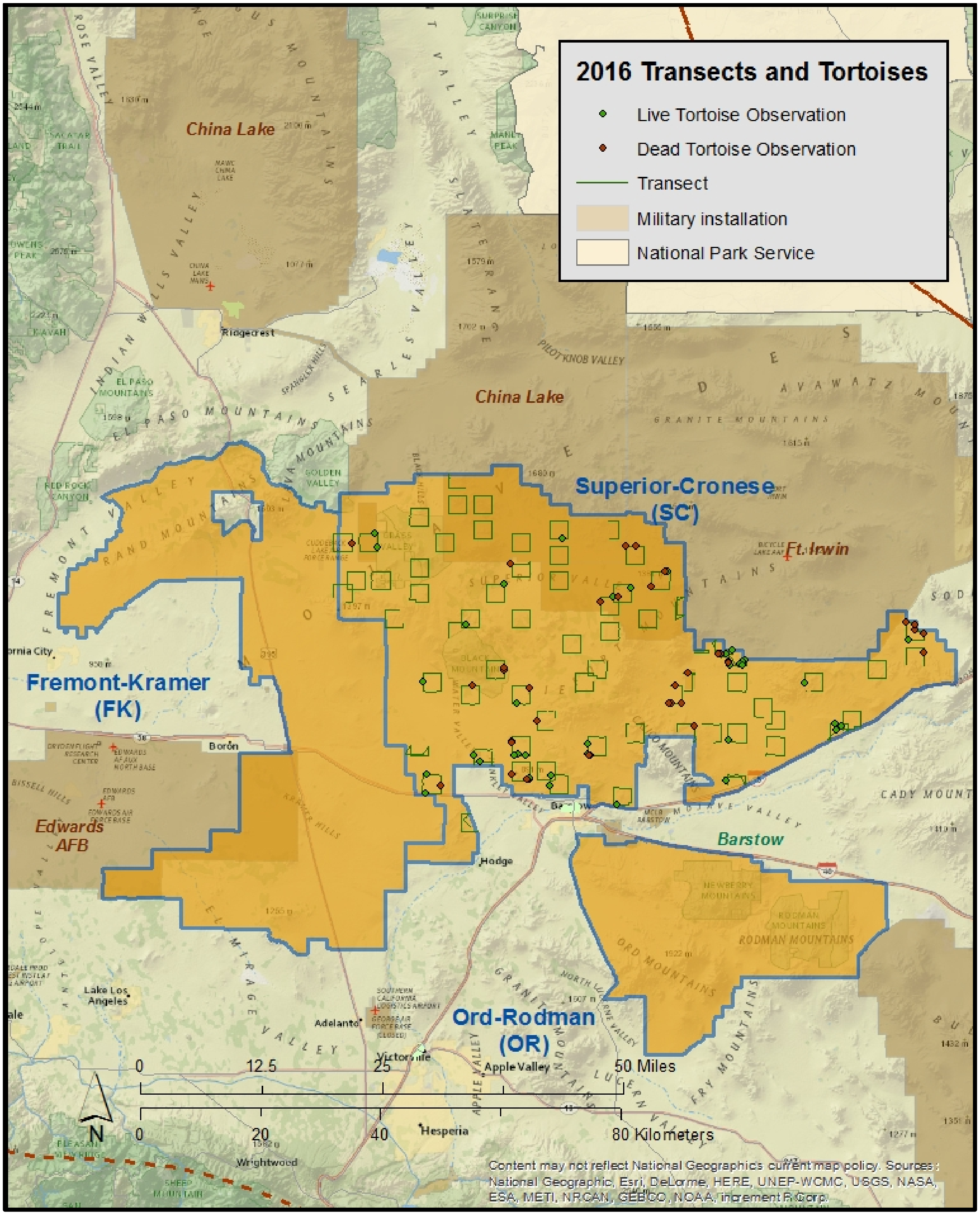

Figure 11. Distribution of distance sampling transects and live tortoise observations in 2016 in the Superior-Cronese stratum in the Western Mojave Recovery Unit.

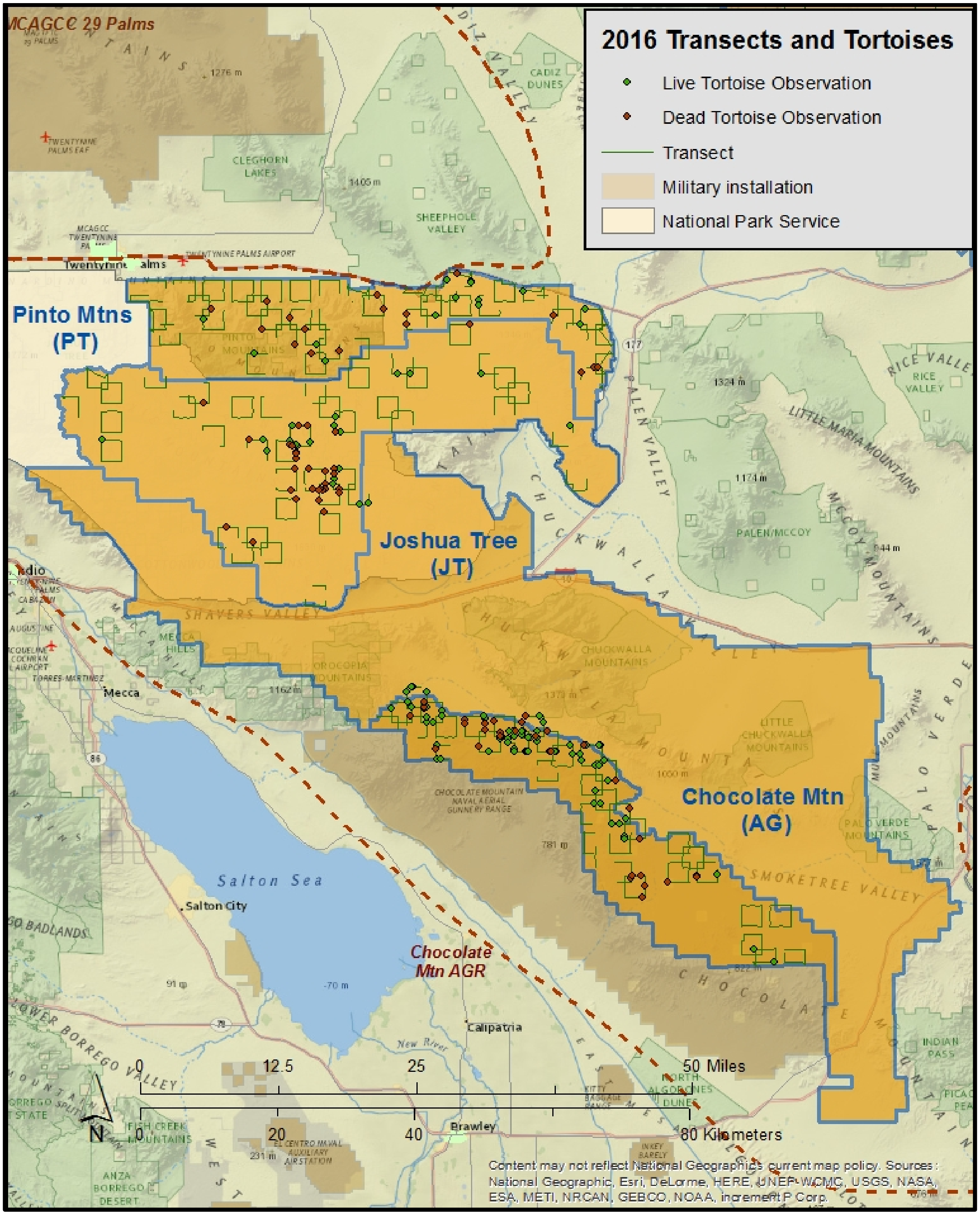

Figure 12. Distribution of distance sampling transects and live tortoise observations in 2016 in the Chocolate Mountain Aerial Gunnery Range, Pinto Mountains, and Joshua Tree strata of the Colorado Desert Recovery Unit.

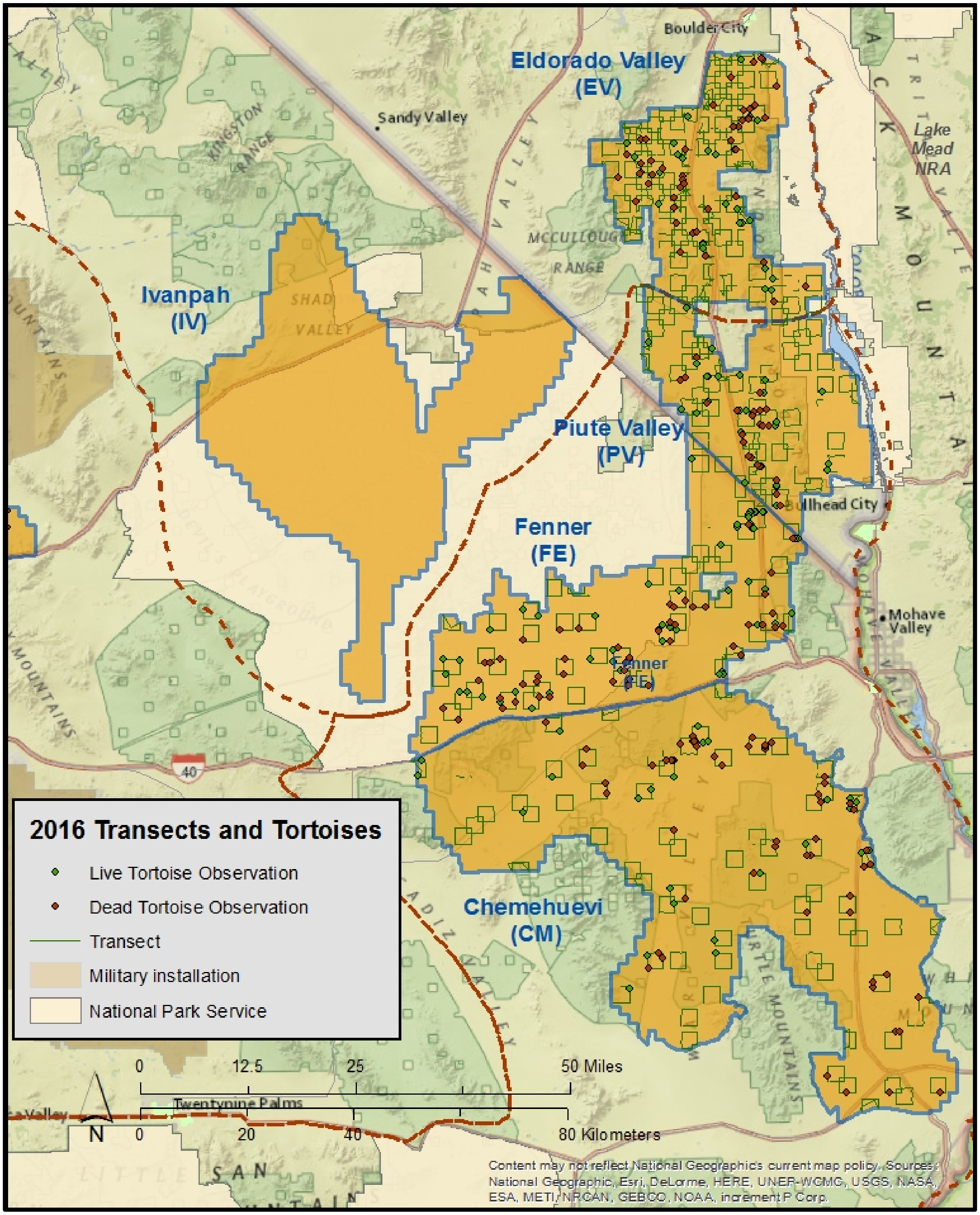

Figure 13. Distribution of distance sampling transects and live tortoise observations in 2016 in the Eldorado Valley stratum of the Eastern Mojave Recovery Unit and in the Chemehuevi, Fenner, and Piute Valley strata of the Colorado Desert Recovery Unit.

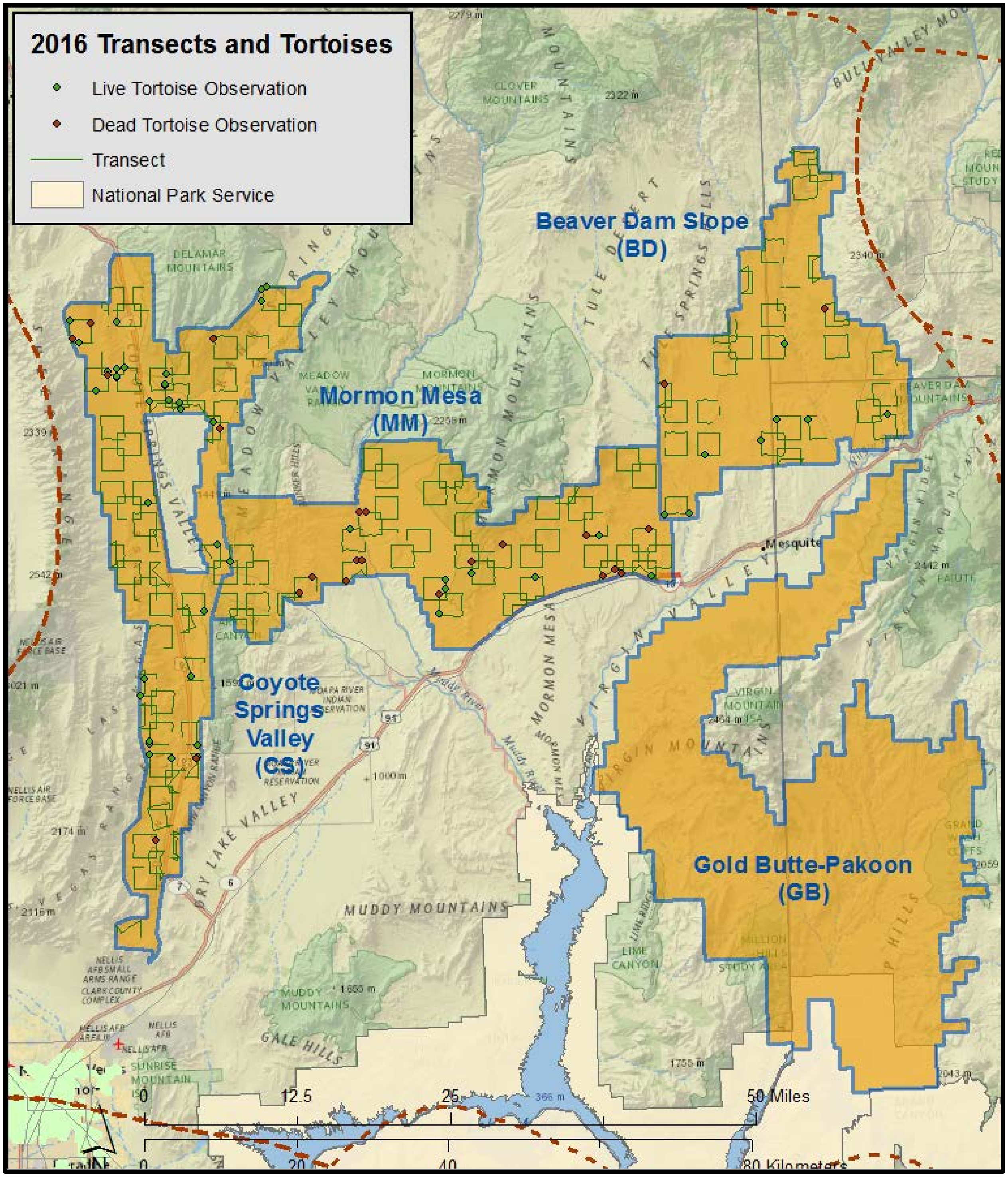

Figure 14. Distribution of transects and live tortoise observations in 2016 in the Beaver Dam Slope, Mormon Mesa, Coyote Springs Valley strata of the Northeastern Mojave Recovery Unit. Under the Lincoln County Habitat Conservation Plan, additional private land in Coyote Springs Valley is under development. Tortoise habitat has effectively decreased by 92 km^2, area that is no longer surveyed.

Proportion of tortoises available for detection by line distance sampling, G_0

In general, telemetry sites and associated strata were completed sequentially, from south to north. This pattern corresponds to the expected timing of tortoise activity; peaking first in the south, later in the north. Visibility from the Chuckwalla telemetry site is usually highest in March and early April, consistent with the estimates for the given dates in 2015 and 2016 (Table 7). Tortoise activity in the eastern part of the range is generally lower than in the west, but G_0 estimates for Coyote Springs in 2015 and for Ivanpah in both years were average-to-high compared to previous years. The estimate for Superior Cronese in 2016 was notably depressed.

Table 7. Availability of tortoises (G_0) when transects were walked in 2015 and 2016 in each group of neighboring strata.

G_0 site	Strata	Dates	Days	G_0 (Std Error)
Superior-Cronese	Superior-Cronese	25 Mar – 13 Apr 2015	20	0.98 (0.050)
Ivanpah	Ivanpah	13 – 27 Apr 2015	15	0.98 (0.053)
Chuckwalla	Chocolate Mtn AGR North	18 – 20 Apr 2015	3	0.73 (0.116)
Chuckwalla	Chocolate Mtn AGR South	3 – 5 May 2015	3	0.53 (0.117)
Chuckwalla	Chocolate Mtn AGR South	7 – 8 Mar 2016	2	0.83 (0.047)
Chuckwalla	Chocolate Mtn AGR North	9 – 12 Mar 2016	4	0.79 (0.042)
MCAGCC	Pinto Mountain	15 – 20 Mar 2016	4	0.91 (0.054)
Ivanpah	Chemehuevi	20 Mar – 3 Apr 2016	15	0.92 (0.040)
Piute Valley & Ivanpah	Fenner	3 – 11 April 2016	9	0.91 (0.019)
Piute Valley & Ivanpah	Piute Valley	4 – 19 April 2016	16	0.70 (0.090)
Halfway Wash	Mormon Mesa	12 – 19 May 2016	8	0.64 (0.116)
Joshua Tree NP	Joshua Tree	14 – 20 April 2016	7	0.88 (0.092)
Halfway Wash	Beaver Dam Slope	19 – 26 May 2016	8	0.36 (0.104)
Piute Valley	Eldorado Valley	13 Apr – 2 May 2016	20	0.72 (0.204)
Superior Cronese	Superior Cronese	21 Apr – 2 May 2016	12	0.76 (0.042)
Coyote Springs	Coyote Springs Valley	2 – 11 May 2016	10	0.92 (0.082)

Tortoise encounter rates and detection functions

All survey pairs worked together from the beginning to the end of the season. In 2015, each Kiva crew walked on a median 35 transects (one team walked 32 and another 34) and overall they detected 134 tortoises larger than 180 mm MCL.

Figure 15 is a histogram of the observed number of tortoises seen at increasing distance from the transect centerline in 2015. Truncation was conservative to maximize the number of observations per stratum. Use of only observations within 20 m allowed a model with no extra inflections and with all but 4% of the observations. At this distance, the hazard-rate model with no adjustments had the lowest AICc, the fit within 6 m of the line was excellent, and the negative exponential model did not have better support (ΔAICc = 2.77), so the detection curve was easy to select. The area below the curve is the proportion of tortoises that were detected, P_a; the teams detected 35.7% (CV=0.132) of the visible tortoises within 20 m of the centerline in 2015.

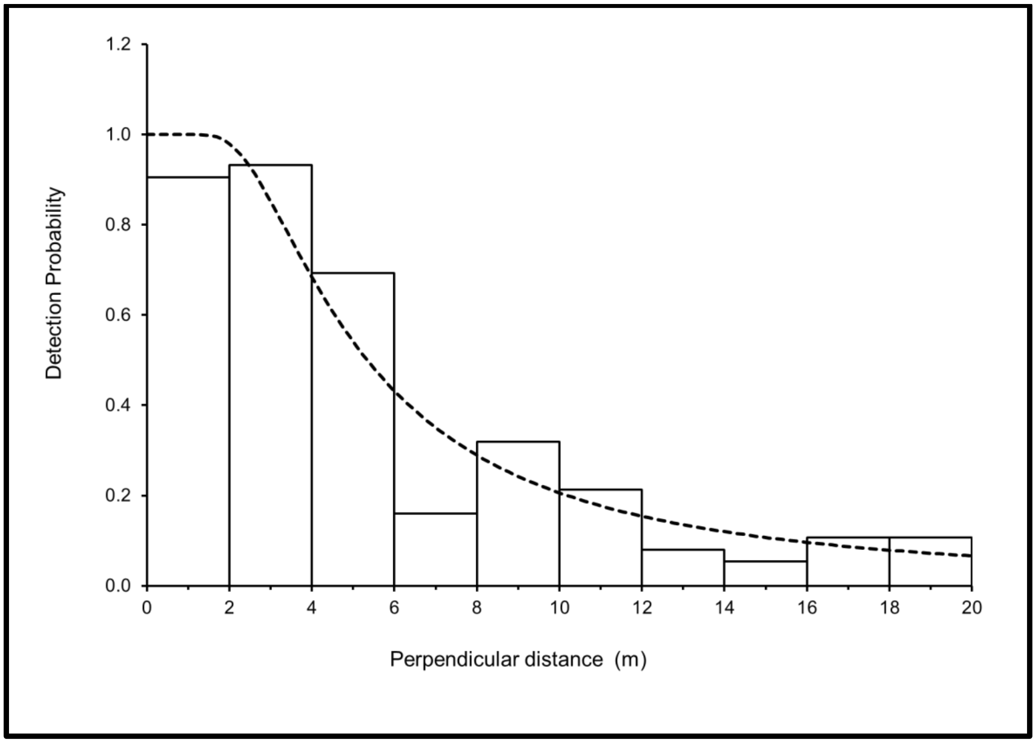

Figure 15. Observed detections (histogram) and the resulting detection function (smooth curve) for live tortoises with MCL ≥ 180mm found in 2015 by Kiva (n=134). This curve uses only observations found within 20 m of the transect center line.

In 2016, GBI surveyors walked a median 43 [30,49] transects each and Kiva walked a median of 60.5 [59,68]. Since both teams had 95% of their observations within 18 m of the transect centerline, I tested a single detection curve against separate curves for each group. In the end, Kiva's detection pattern best fit a uniform model with 1st and 2nd order cosine adjustments and GBI best fit an unadjusted hazard rate curve (although the negative exponential model was within 0.98 AIC units). The joint detection curve had ΔAIC = 18.34. Figure 16 and 17 are histograms of the observed number of tortoises seen at increasing distance from the transect centerline. Truncation at 18 m was conservative to maximize the number of observations per stratumand resulted in detections with good fit near the centerline and minimum adjustment terms to fit the handful of observations in the tails. The detection rate for crews within 18 m of the transect centerline was 49.5% (Kiva; CV=0.076) and 17.7% (GBI, CV=0.202).

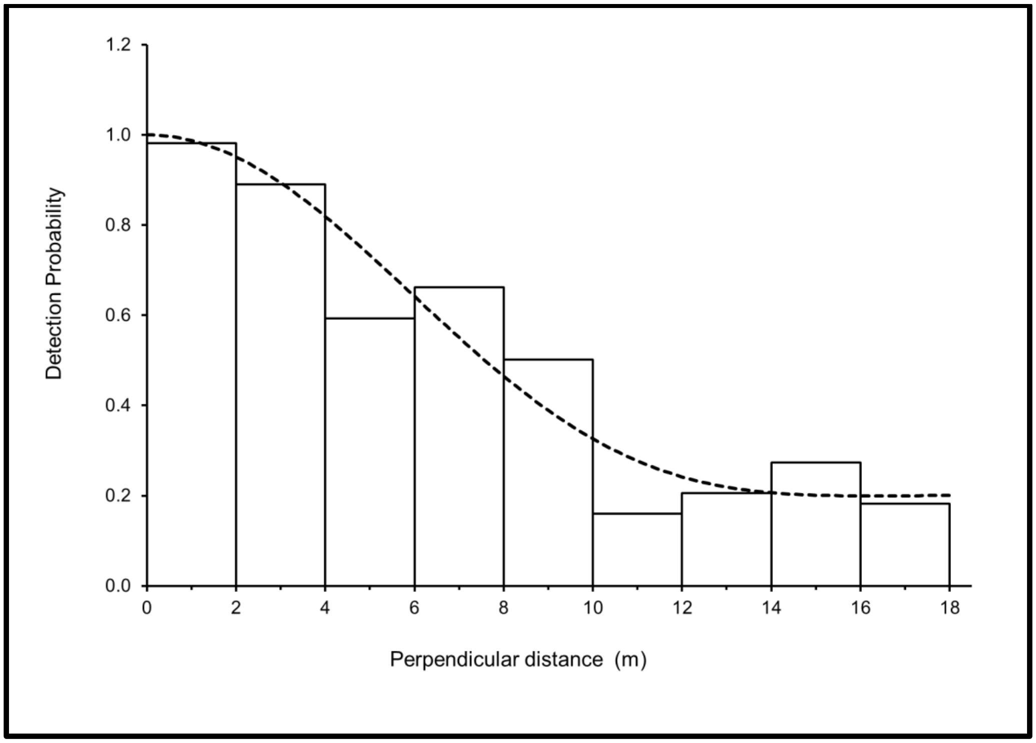

Figure 16. Observed detections (histogram) and the resulting detection function (smooth curve) for live tortoises with MCL ≥ 180mm found by Kiva in 2016. This curve uses only the n=195 observations found within 18 m of the line.

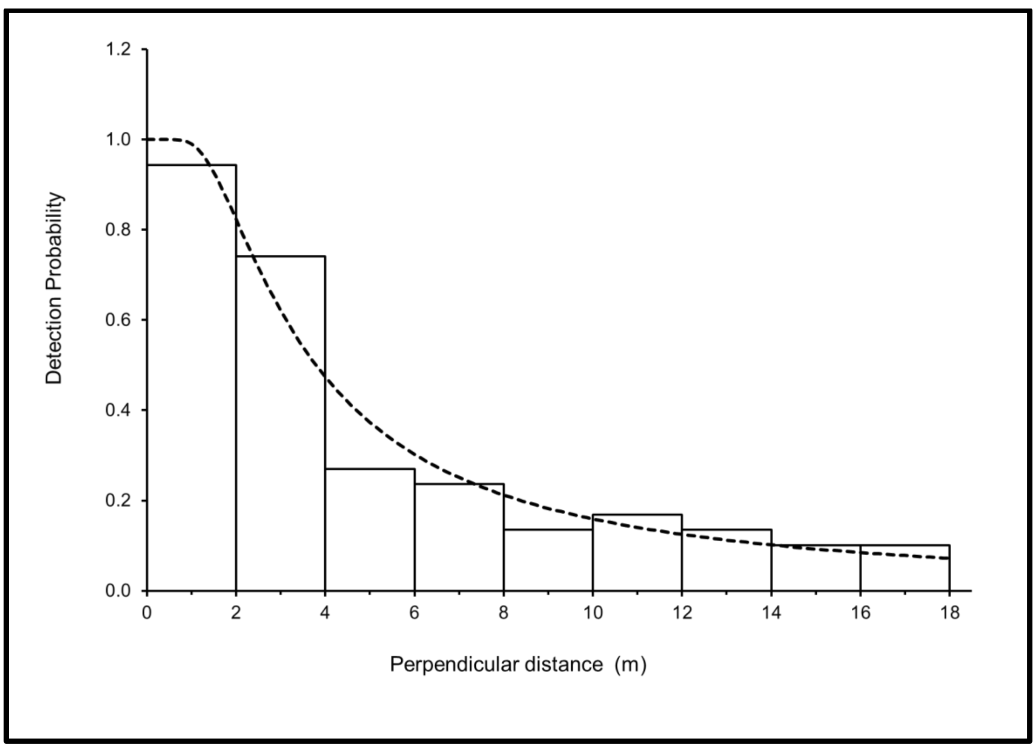

Figure 17. Observed detections (histogram) and the resulting detection function (smooth curve) for live tortoises with MCL ≥ 180mm found by GBI in 2016. This curve uses only the n=84 observations found within 18 m of the line.

Proportion of available tortoises detected on the transect centerline, *g(0)*

Because they are cryptic, even tortoises that are visible (not covered by dense vegetation or out of sight in a burrow) and close to the surveyor may not be detected. In 2015, for 81 detections of tortoises within 5 m of the transect centerline, 72 were found by the observer in the lead position and 9 by the follower, so that the probability of detection by single observer, $p = 0.875$, and the proportion detected using the dual observer method, *g(0 to 5 m)* = 0.984 (SE = 0.063). In 2016, 23 of 125 observations within 5 m of the centerline were found by the follower, and $p = 0.816$ with *g(0 to 5m)* = 0.916 (SE = 0.060). Figure 18 shows that *g(0)* was converging on 1.0 in both 2015 and 2016, indicating the assumption of perfect detection on the centerline was met; consequently, no adjustment was made to the final density estimate. The curves since dual observers were first used in 2004 have all supported the premise that complete detection on the transect line was achieved for years in which the dual-observer method was used (USFWS 2009, 2012a, 2012b, 2013, 2014, 2015).

Estimates of tortoise density

Density estimates were generated separately for each monitoring stratum (Table 8).

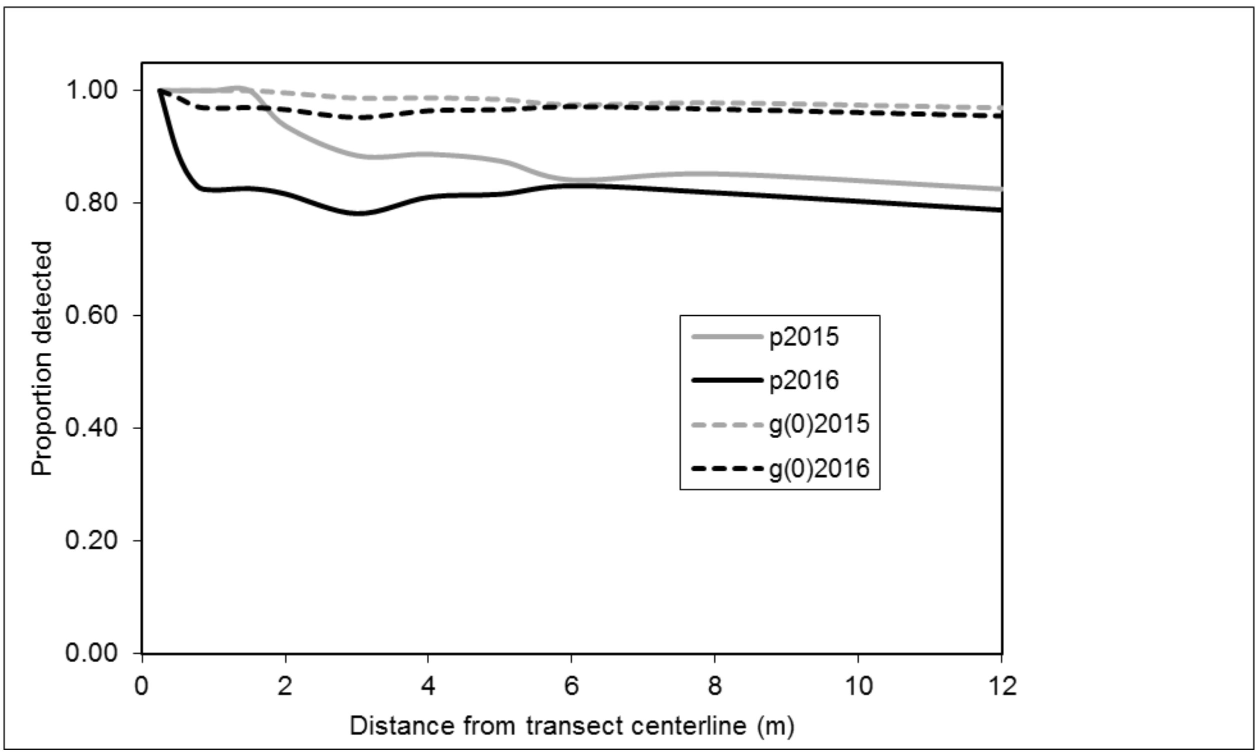

Figure 18. Detection pattern for the leader (*p*) and by the team (*g(0)*) based on all observations out to a given distance (*x*) from the centerline in 2015 and 2016. Note convergence of *g(0)* on 1.0 as *x* goes to 0.

Table 8. Stratum-level encounters and densities in 2015 and 2016 for tortoises of MCL ≥ 180 mm within 18 m of the centerline. Coefficients of variation expressed as percentages.

Recovery Unit & Year	Stratum	Area (km2)	Number of Transects	Total transect length (km)	Sampling Dates Begin	Sampling Dates End	Field Observers	*n* (tortoises observed)	CV(*n*)	Density (/km2)	CV(Density)
Colorado Desert - 2015		**755**									
Chocolate Mountain	AG	755	36	406	18-Apr	5-May	Kiva	39	17.0	10.3	21.1
Eastern Mojave - 2015		**1124**									
Ivanpah	IV	1124	74	882	13-Apr	27-Apr	Kiva	23	20.4	1.9	24.3
Western Mojave - 2015		**5748**									
Fremont-Kramer	FK	2417	60	714	31-Mar	13-Apr	Kiva	43	21.5	4.5	28.0
Superior-Cronese	SC	3332	70	799	25-Mar	13-Apr	Kiva	29	22.9	2.6	26.7
Western Mojave - 2016		**3332**									
Superior-Cronese	SC	3332	69	765	20-Apr	2-May	Kiva	37	24.5	3.6	26.3
Colorado Desert - 2016		**10,022**									
Chocolate Mountain	AG	755	36	383	7-Mar	12-Mar	Kiva	60	18.7	8.5	20.7
Chemehuevi	CM	4038	70	804	20-Mar	3-Apr	Kiva	22	29.3	1.7	30.6
Fenner	FE	1841	50	586	3-Apr	11-Apr	Kiva	46	24.5	5.5	30.0
Joshua Tree	JT	1567	41	410	11-Apr	20-Apr	Kiva	17	32.2	2.6	34.7
Pinto Mountain	PT	751	40	385	14-Mar	20-Mar	Kiva	13	30.1	2.1	31.6
Piute Valley	PV	1070	51	600	4-Apr	19-Apr	GBI	22	24.3	4.0	35.3
Eastern Mojave - 2016		**1153**									
Eldorado Valley	EV	1153	89	1002	13-Apr	2-May	GBI	22	22.6	2.7	41.5
Northeastern Mojave - 2016		**2913**									
Beaver Dam Slope	BD	828	28	310	19-May	26-May	GBI	7	33.4	5.6	50.7
Coyote Springs Valley	CS	1025	54	593	2-May	11-May	GBI	26	21.7	4.2	31.0
Mormon Mesa	MM	968	42	458	12-May	19-May	GBI	7	40.3	2.1	47.9

Area of each stratum sampled

Evaluating transect classification

In 2015 and 2016, crews surveyed 240 and 570 transects, respectively. Of these, 136 (2015) and 210 (2016) of the walked transects had not been surveyed in the past. Over the two years, 145 of the 810 walked and 91 unwalked transects were not completed or addressed as predicted. Table 9 summarizes conclusions after examining these transects. Eleven of the 145 were reclassified based on crew experience. In some cases, this reflects a discrepancy between on-the-ground conditions and interpretation of terrain from imagery; in others, classification is ambiguous because over the course of a 12-km transect, terrain is so variable that it was not a simple matter to evaluate the ability of a typical crew to complete it. The remaining 134 anomalous transects were not reclassified, because earlier experience indicated that most crews would use the original completion strategy. The 11 transects that were reclassified represent 0.3% of the 3207 potential transects in the long-term monitoring strata, so there is very little impact on our estimate of the proportion of each stratum that is walkable.

Table 9. Transects completed other than as planned and any resulting reclassification

Previous substratum	Situation in 2016	New substratum	# transects 2015	# transects 2016
12k	Shortened on military base due to operations	No change	7	14
12k	Time or access caused shortened transect	No change	0	5
12k	Shortened but in future may be 12k	No change	10	31
12k	Crew observation indicates only shortened transect possible	Shortened	6	1
12k	Unwalked in this period but completion possible	No change	7	1
Shortened	Crews walked 12k, but may not be repeatable	No change	12	26
Shortened	Not walked but alternate completion possible	No change	8	11
Unwalkable	Crew observation indicates shortened transect possible	Shortened	0	1
Shortened	Unwalked now and more often in past	Unwalkable	0	2
Unwalkable	Crew completion not expected in future	No change	1	1
Unwalkable	Crew report contradicts remote imagery	12k	0	1

DISCUSSION

One priority for the next years will be to determine whether there is a pattern of tortoise activity moving to earlier in the season in any parts of the range. This will inform the optimal timing of surveys but is of course of more significance for interpreting other measures of biological response to climate change.

The stratum-level density estimates from these two years of surveys will be evaluated every five years with those since the beginning of the surveys in order to test for and describe population growth trajectories. The next evaluation of population trends is planned after the 2019 field season.

Monitoring of declining populations should be deeply integrated in conservation and recovery programs. Although these surveys were designed to provide a 25-year description of a positive population growth trend, it is clear that this single purpose would be an underutilization of the program which can certainly address interim management questions (Nichols and Williams, 2006). Population recovery will necessitate accelerated, prioritized recovery activities (Darst et al., 2013). Targeted effectiveness monitoring (Lyons et al., 2008; Lindenmayer et al., 2010), where possible, will complement this larger monitoring program that provides a composite view of all recovery activities in each stratum. Both types of monitoring will be needed to characterize the effectiveness of recovery activities where the list of threats is so large and their interactive effects can be complex.

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